ARR No. 3F12

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

June 1943 as
Advance Restricted Report 3F12

SOME SYSTEMATIC MODEL EXPERIMENTS ON THE PORPOISING CHARACTERISTICS OF FLYING-BOAT HULLS

By Kenneth S. M. Davidson and F. W. S. Locke, Jr.
Stevens Institute of Technology

2.2
2.3.4
2.3.5
2.10.1

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

SOME SYSTEMATIC MODEL EXPERIMENTS ON THE PORPOISING CHARACTERISTICS OF FLYING-BOAT HULLS

By Kenneth S. M. Davidson and F. W. S. Locke, Jr.

SUMMARY

This report presents the results of systematic model experiments on the hydrodynamic characteristics of flying boats, aimed primarily at developing a comprehensive view of the factors influencing porpoising and of their relative importance. The experiments "radiated" from a given reference ship; they embrace changes, over reasonably wide ranges, in the value of each of a number of variables, treated independently.

The experimental results are summarized in a series of 25 figures, each of which gives the complete data for all the modifications of one variable.

The results are further condensed for easy reference in charts 1 to 3, which follow the Summary. In these charts the principal portions of the summary figures are reproduced at smaller scale and are arranged in groups according to the type of the variable they represent. Here the relative influence of the variables is brought out merely by the relative "blackness" of the charts.

The major conclusions which follow are based upon the ranges of change of the variables indicated on the summary figures:

1. The stability limits for a given hull under various loadings and aerodynamic conditions are determined (1) primarily by the three variables which govern the load on the water in steady motion - gross load Δ_0, wing lift at arbitrary trim angle Z_0, and rate of change of lift with

---

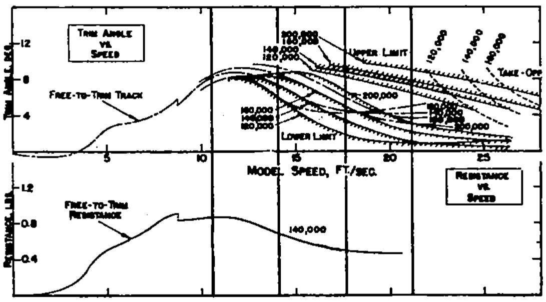
The complete set of data from which the figures in this report were prepared and on which the analyses in this report were made may be obtained on loan from the Office of Aeronautical Intelligence of the National Advisory Committee for Aeronautics, Washington, D. C.

trim Z_θ and (2) secondarily by the tail damping rate M_q. Increasing the water-borne load raises both limits without materially affecting the width of the stable range; increasing the tail damping rate lowers the lower limit at high speeds - the magnitude of the effect being greatest, however, at damping rates considerably below normal.

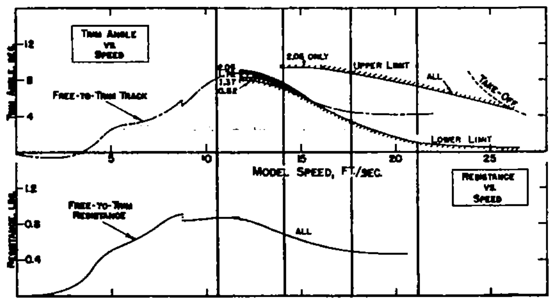
2. Alterations to the afterbody, under given loading and aerodynamic conditions, may alter the upper limit and the peak value of the lower limit in the vicinity of the hump; they do not alter the lower limit at higher speeds. The hump trim and the hump resistance in steady motion follow the variation of the peak of the lower limit. Assuming a reasonable length, the most powerful afterbody variable is the angle between a prolongation of the forebody keel and a line joining the tip of the main step with the tip of the stern post. Increasing this angle raises the hump trim and resistance and the upper limit of stability; if carried far enough, it will suppress upper-limit porpoising at high speeds. Increasing the step height also suppresses upper-limit porpoising at high speeds.

3. Alterations to the forebody, under given loading and aerodynamic conditions, may alter both limits but tend to affect principally the lower limit at high speeds. If sufficient forebody length to provide flotation and to prevent diving at low speeds is assumed, the most powerful forebody variable is the amount of warping of the bottom in the region just ahead of the main step. Increasing the warping lowers the lower limit at high speeds but raises the hump resistance.

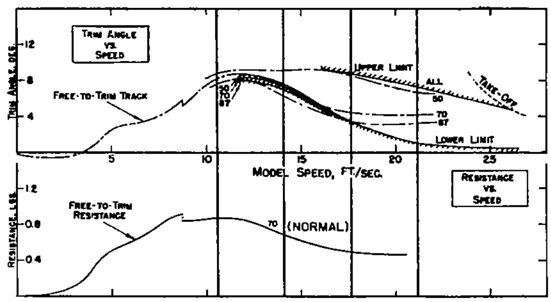
4. Finally, as a tentative, very broad conclusion: None of the modifications considered in the experiments was successful in eliminating completely either upper-limit or lower-limit porpoising and, in general, modifications which tended to improve the porpoising characteristics tended to injure the resistance characteristics. Modifications of the loading or of the aerodynamic conditions (that is, of the variable of groups I and II shown in charts 1 and 2) were found not to affect the characteristics appreciably except as they influenced the net water-borne load; modifications of the hull form (taking group III, chart 3, in its entirety) had larger effects, but these modifications were mainly variations on a given parent form. It follows that any significant improvement in both porpoising and resistance characteristics must depend upon improving the basic parent form of the hull.



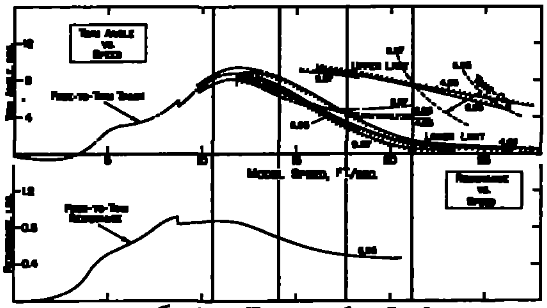
CHANGES OF GROSS WEIGHT, LBS., SEE FIG. 6



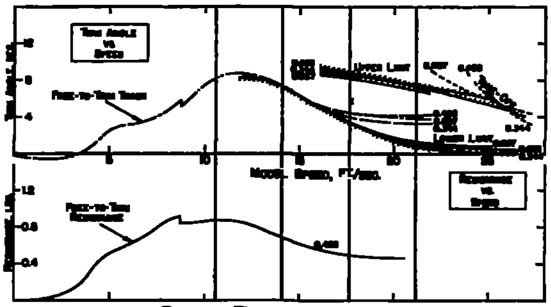
MOMENT OF INERTIA, SEE FIG. 7



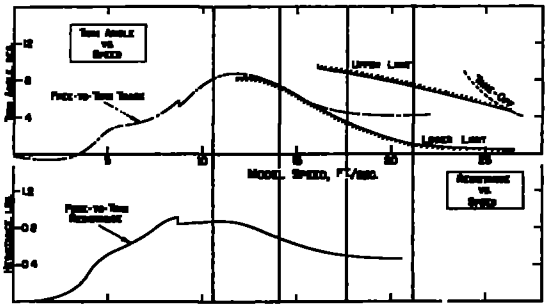
CHANGES OF LONGITUDINAL POSITION OF C.G.
SEE FIG. 8



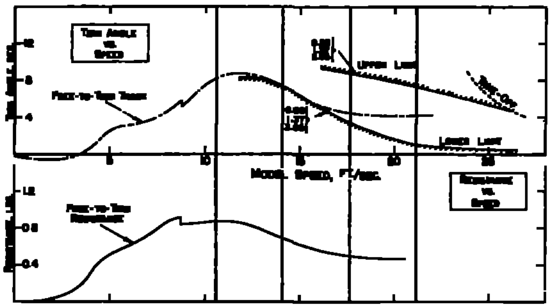
Wing Lift at $\tau = 5°$, Z_o See Fig. 9



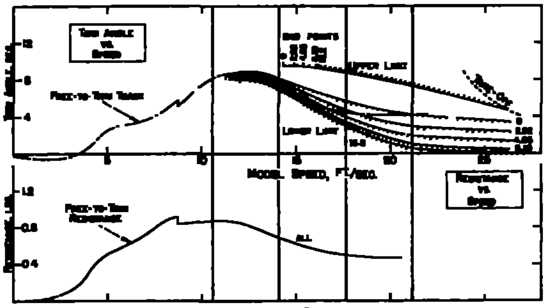
Wing Lift Rate, Z_θ, See Fig 10



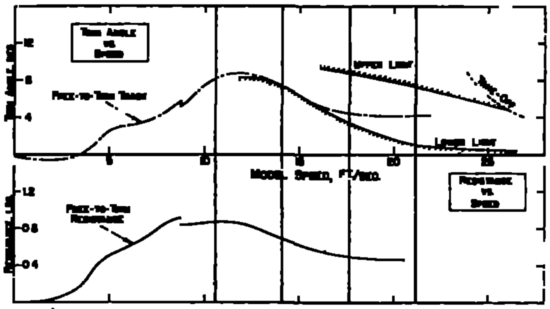
Vertical Velocity Damping, Z_w, See Fig. 11



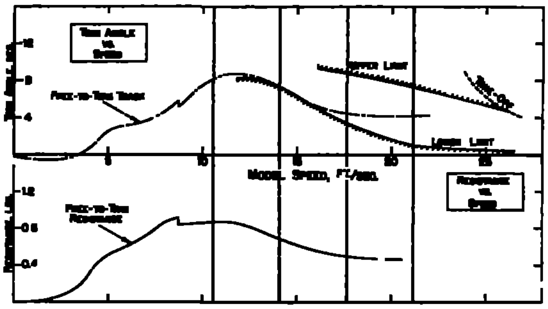
Tail Moment Rate, M_θ, See Fig. 12



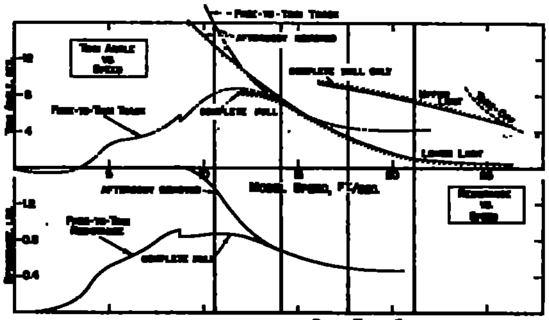
Tail Damping, M_q, See Fig. 13



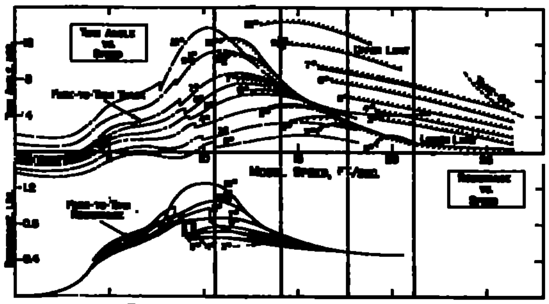
Introduction of 35° Lagging Phase Angle Between qM_q and q, See Fig 14



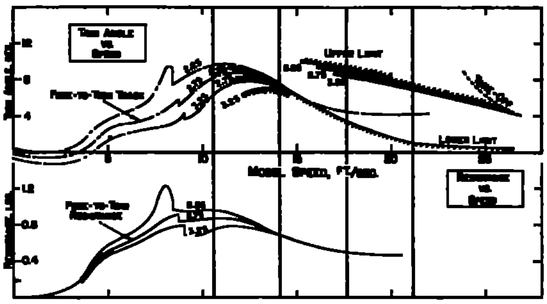
Inclusion of M_w & Z_q with M_q, Compared To M_q Alone, See Fig. 15



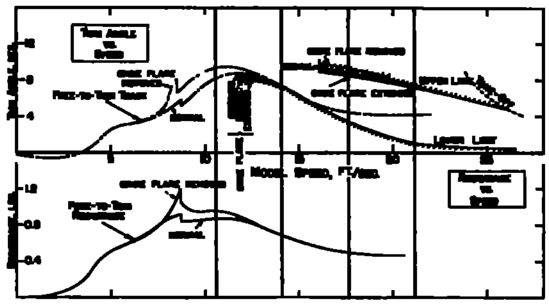
AFTERBODY REMOVED, SEE FIG. 16



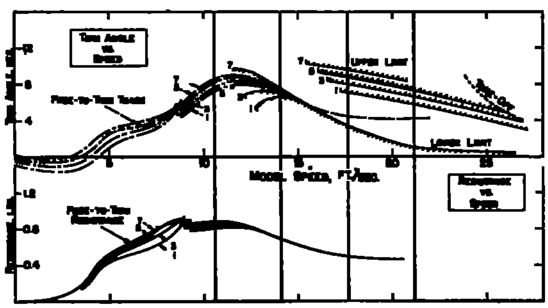
ANGLE BETWEEN FORE AND AFTERBODY KEELS, SEE FIG. 17



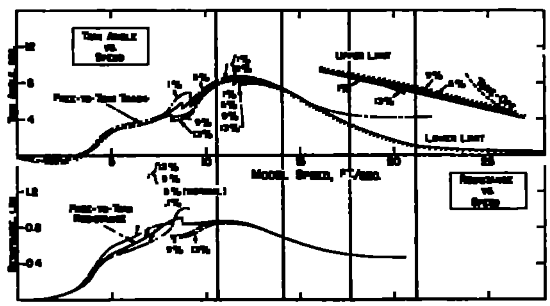
AFTERBODY LENGTH, SEE FIG. 18



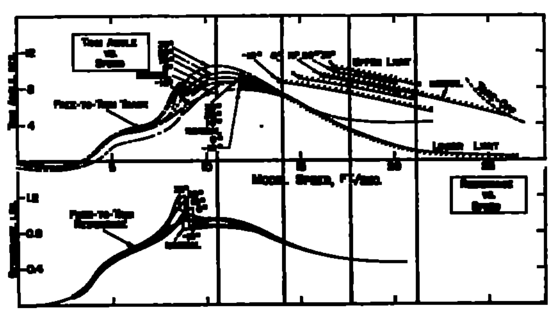
AFTERBODY CHINE FLARE, SEE FIG. 19



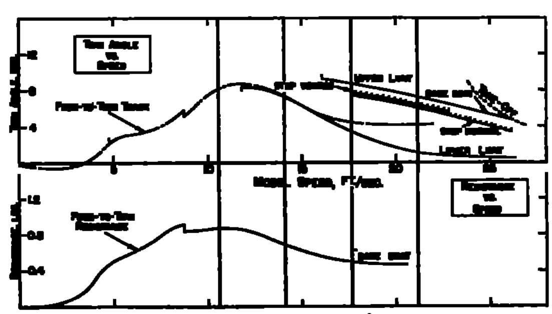
HEIGHT OF MAIN STEP, 1ST SERIES, SEE FIG. 20



HEIGHT OF MAIN STEP, 2ND SERIES, SEE FIG. 21

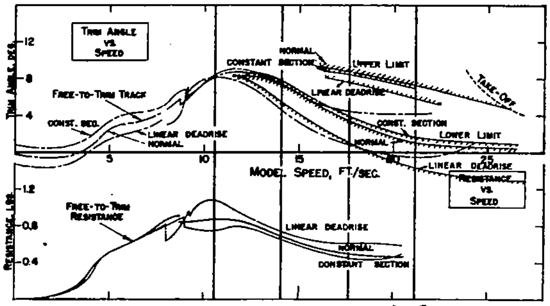


AFTERBODY WARPED, SEE FIG. 22

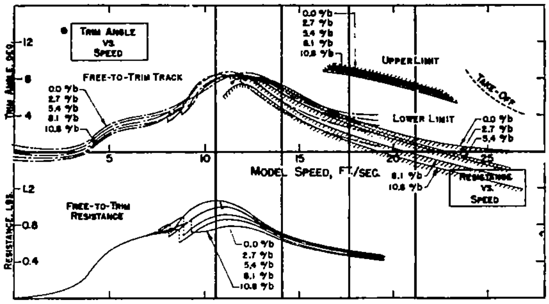


STEP VENTILATION, STEP HEIGHT 1%, SEE FIG. 23

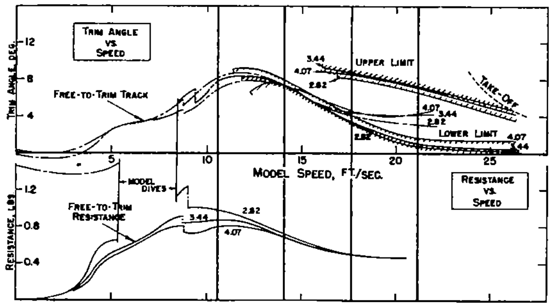
GROUP III F – FOREBODY FORM



FOREBODY FORM (WARPING OF BOTTOM), SEE FIG. 24

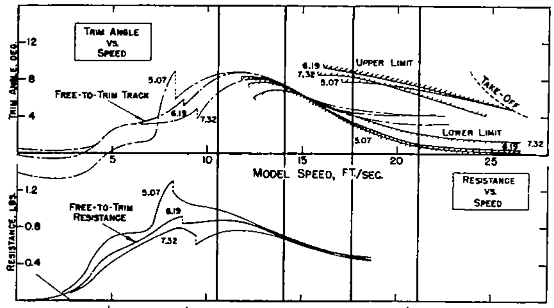


FOREBODY WARPING, SEE FIG. 25

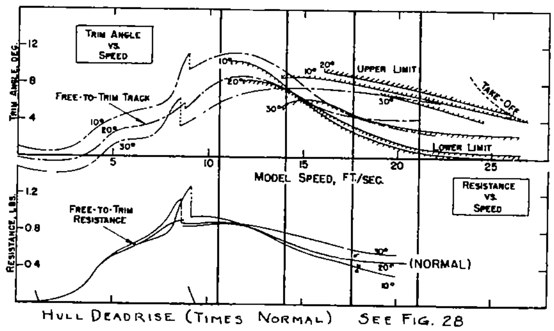


FOREBODY LENGTH (TIMES BEAM AT MAIN STEP)
SEE FIG. 26

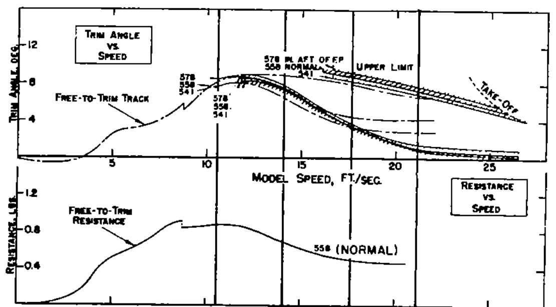
GROUP III H



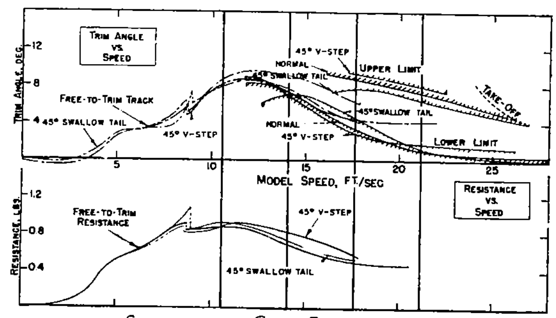
HULL LENGTH (TIMES BEAM AT MAIN STEP) SEE FIG. 27



HULL DEADRISE (TIMES NORMAL) SEE FIG. 28



CHANGES OF LONGITUDINAL STEP POSITION, SEE FIG. 29



CHANGES OF STEP PLANFORM, 45° V-STEP NORMAL,
45° SWALLOW TAIL, SEE FIG. 30

INTRODUCTION

Porpoising is a self-sustaining oscillatory motion in the vertical longitudinal plane, which occurs at planing speeds. It can originate in an instability of the uniform longitudinal motion in smooth water and does not depend for its persistence upon any system of periodic disturbing forces such, for instance, as is provided by head seas. In the words of one test pilot, "It is always unpleasant and it may be catastrophic."

Observations of porpoising show that there are really two principal oscillatory motions (1) a vertical oscillation of the center of gravity and (2) an angular oscillation about the center of gravity. These two motions are seen to have the same period but to differ in phase. The necessary energy to sustain porpoising must evidently be drawn from the horizontal propelling force, there being no other possible source. The average water resistance must therefore be greater than for steady motion under the same conditions if the speed is held constant, or the average speed must be less if the propelling force is held constant. In the latter event, an oscillation in the horizontal speed may be added to the two motions described above, but this is usually small and may ordinarily be disregarded.

Two main classifications of porpoising are distinguishable with hulls of conventional type:

(1) Low angle or "lower-limit" porpoising, which occurs at relatively low trim angles, is clearly attributable to instability of the forebody planing alone and is largely uninfluenced by the afterbody

(2) High angle or "upper-limit" porpoising, which occurs at relatively high trim angles, is clearly attributable to interaction between the forebody and afterbody and is influenced in important respects by changes in the afterbody form

There is usually a region of stable trim angles between the regions in which these two classes of porpoising occur. The stable region is conveniently described by a statement of the trim angles at the upper and lower "limits of stability." The objective in designing is to eliminate porpoising or, failing this, to widen as much as possible the range of stable trim angles between the two limits.

Porpoising phenomena have been studied by theoretical analysis of the conditions for stability, starting from the basic equations of motion (references 1 and 2). To date, this approach has failed to advance materially a detailed understanding of the phenomena, and it requires so much time-consuming labor as to render its practical application in individual cases nearly prohibitive.

Most of what is now known about porpoising has been learned through model experiments conducted with due regard to the dynamic requirements. The inherent danger to the actual ship limits the scope of systematic experiments on porpoising at full scale, and model experiments have the additional advantage that the test conditions can be more accurately controlled and the test results therefore more readily interpreted. Sufficient evidence exists to indicate satisfactory correlation between ship and model porpoising in basic respects.

Because of the inherent danger to the ship and the consequent need of advance warning on porpoising characteristics, model experiments in the past have tended to place the emphasis on predicting the characteristics of individual designs rather than on developing a broad picture of the influence and relative importance of the various factors involved. The latter point of view was adopted for the investigation which forms the subject of this report. In addition, through simplification of the testing procedure and the use of an unusually small model, the experimental work has been materially accelerated so that considerable ground can be covered in a short time.

The experiments followed a program designed primarily to gain perspective, and considerable attention has been given to presenting the test results in simple form. Only the basic porpoising characteristics are considered; namely, the upper and lower limits, as these would be determined in an actual ship by respectively raising or lowering the trim angle from a mean value in the stable range. Variations, particularly of the high-angle type of porpoising, are known to exist; these have been disregarded for the present in the interest of clarifying the basic types.

The work was undertaken with the financial assistance of the National Advisory Committee for Aeronautics. The program originally laid out was to parallel similar work contemplated by them. In the course of two years the program has been expanded considerably along independent lines.

SCOPE OF INVESTIGATION

It is the purpose of this report to present the results of certain systematic model experiments on flying-boat hulls. Porpoising characteristics and steady-motion resistances are considered, but the principal emphasis is on the porpoising characteristics. The experiments radiated from a given flying boat, taken as a basic point of departure. The reference ship used was the XPB2M-1, a representative modern design having, for a gross weight of 140,000 pounds, a wing loading Δ_0/S of 38.0 pounds per square foot, and a beam loading Δ_0/wb^3 of 0.89. Each of a number of variables was altered, separately from the others as far as possible, over a range of values embracing the normal value for the reference ship and intended to be wide enough to cover all values likely to be encountered in practice. The advantage of this procedure is that it materially simplifies the problem of coordinating test results. It does not necessarily restrict the applicability of the results to the reference ship - provided that the ranges of change of the variables are sufficiently wide.

The radiating chart (fig. 1) shows the three groups into which the variables fall naturally:

Group I - Weight and Inertia Loading
Group II - Aerodynamic Conditions
Group III - Hull Form

and also the component variables of each group which have been covered, to date, by the experiments. It will be seen that the last group is subdivided into

Group IIIA - Afterbody Form
Group IIIF - Forebody Form
Group IIIH - Hull Form (As a Whole)

The dimensions and particulars considered as "normal" for ship and model (1/30 scale) are given in table I. The basic hull lines are shown in figure 2.

Condensed summary figures of test results (figs. 6 to 30) include all the pertinent data; all conclusions or generalizations are based on the ranges of change of the variables which they show. Had the ranges of changes been extended "ad absurdum," some of the conclusions and generalizations would undoubtedly have been altered.

TEST METHOD

Tests of a dynamic model, complete with wings and tail surfaces, are a recognized method of investigating the porpoising characteristics of individual flying-boat and seaplane designs (references 3 and 4). Difficulties inherent in this method are

(1) That the magnitudes and the influence on porpoising of the separate aerodynamic and hydrodynamic components of the variables involved are not easily evaluated

(2) That scale or interference effects may easily prevent accurate reproduction of the full-size aerodynamic forces and moments

(3) That the time and cost involved in constructing and altering models is high

The method used in the present investigation was designed to overcome these difficulties as far as possible and to permit direct studies of the hydrodynamic characteristics under rigidly controlled "aerodynamic" conditions. A dynamic model of the hull is used without wings or tail surfaces. The equivalent of the aerodynamic forces and moments are applied by

(1) A calibrated hydrofoil for lift forces and force derivatives

(2) A calibrated spring and a calibrated dashpot for aerodynamic moments and moment derivatives

All these are readily adjustable to produce magnitudes corresponding to any desired air structure.

DESCRIPTION OF APPARATUS

A diagrammatic sketch and a photograph of the apparatus used in the porpoising experiments are shown in figures 3 and 4.

The main frame is fitted with vertical tracks guided by rollers so that it is free to move vertically but otherwise restrained with respect to the towing carriage of the tank. The model is attached to the forward end of this frame through pivots at the center of gravity which allow freedom in pitch; the after end of the frame carries the supporting column for a hydrofoil. This frame transmits the lift of the hydrofoil to the model; its weight, with all the attachments moving with it, is a part of the gross weight of the model.

The walking beam, pivoted on the main frame, changes the angle of attack of the hydrofoil in proportion to changes in the angle of trim of the hull. Through the design of the hydrofoil itself, and by means of the adjustments provided, the aerodynamic lift can be made to correspond to prescribed values of

Z_o lift at arbitrary trim angle (L_o)

Z_θ rate of change of lift with trim angle ($dL/d\tau$)

Z_w rate of change of lift with vertical velocity (dL/dw)

A torsion spring, mounted in the axis of the model pivot, is provided with the necessary adjustments for making the resultant aerodynamic moment correspond to prescribed values of

M_o moment at arbitrary trim angle (M_o)

M_θ rate of change of moment with trim angle ($dM/d\tau$)

The dashpot shown is provided with a number of calibrated pistons which, together with adjustment of the radius of action, provide for making the aerodynamic tail damping moment correspond to prescribed values of

M_q rate of change of moment with angular velocity (dM/dq)

The following two aerodynamic derivatives are neglected in this arrangement of the apparatus:

Z_q rate of change of lift with angular velocity (dL/dq)

M_w rate of change of moment with vertical velocity (dM/dw)

A series of special tests described later, confirmed the assumption made in designing the apparatus that these two derivatives probably had negligible effects on the stability limits.

Graphical records of porpoising are obtained from a scriber, attached to the model and located at an arbitrary height directly above the center of gravity when $\tau = 0$, which moves over a smoked glass fixed with respect to the towing carriage. The records are reproduced photographically.

The drive gear of the Stevens Tank is arranged to provide a series of fixed, reproducible speeds. A description of the tank will be found in reference 5.

TEST PROCEDURE

All tests were made at constant speeds and in substantially still water. It is considered that tests at a steady speed are more likely to bring out porpoising tendencies than accelerated tests, because they allow time for any instability to develop. In all cases in which propoising occurred, a steady-state cycle was developed after a very few initial transient cycles. It was found that the transient cycles depend upon the amplitudes of the initial disturbances which start porpoising, as compared with the steady-state amplitudes, a larger number of transient cycles occurring when the initial disturbances are relatively small and a smaller number when the initial disturbances are relatively large.

The amplitude of the final steady-state cycle is largely unaffected, however, by the magnitude of the initial disturbances and is therefore a convenient measure of the inherent porpoising tendency under given conditions. The principal requirement in testing is that the initial disturbances shall be sufficiently severe to insure development of the steady state within the limits of the test run. To this end the model is accelerated rapidly in a distance equal to about three or four times its own length.

The tests under each combination of hull form, aerodynamic conditions, and loading followed the same basic program. In detail:

(1) Tests were made at each of a number of fixed speeds, covering the range from a little below the

hump to get-away in approximately equal steps.

(2) At each speed, tests were made with variations of the applied moment (corresponding to resultant aerodynamic moment), covering a range sufficient to produce trim angles embracing the upper and lower stability limits, as ordinarily defined. The moment setting (corresponding to elevator setting) was not altered during the course of any one test.

(3) At each speed and applied moment, a test was made with each of three values of the tail damping dM/dq corresponding consecutively to one-half, one, and two times the normal value given in table I, unless stability occurred with less than the maximum of these values. In the latter event no further tests were made. When the maximum value failed to cause stability, an additional test was made with a large excess of tail damping to define the steady-motion attitude.

(4) The tests with normal particulars were made first and were carried out very completely. In the later tests with modified particulars, certain cases were omitted which the first tests had shown to be relatively unimportant.

(5) Graphical records were made of the steady-state, fully developed, porpoising cycle for all tests in which propoising occurred.

(6) The stability limit is arbitrarily defined as the trim at which the total sweep in trim angle during porpoising (that is, the double amplitude) is 2°. This definition is of greatest significance in connection with lower-limit porpoising, where the amplitude tends to blow up progressively; in the case of upper-limit propoising, which tends to start suddenly and may often consist principally of vertical motion, an arbitrary definition of the stability limit is largely unnecessary.

The limits shown in the charts are for normal tail damping, and are lifted from auxiliary charts of the sweep measured on the graphical records against the steady-motion trim angle, at constant speed.

ACCURACY

The accuracy of the readings from the various parts of the apparatus and towing gear has been checked by frequent calibration, and it is believed that the values used in preparing the curves are correct within the following limits:

Speed, foot per second	±0.01
Resistance, pound	±0.01
Trim, degree	±0.3
Trimming moment, pound-inch	±0.1
Displacement, pound	±0.05

Another method for appraising the accuracy of the tests is to compare the reproducibility of fully developed porpoising cycles. When the apparatus was first put into use, this matter was given considerable attention. It was found that records of porpoising cycles obtained at intervals of several months, under presumably identical conditions, were as nearly alike as they could be measured. In a more recent case, two models built to the same lines and tested 2 years apart gave practically identical results over the entire speed range. Thus it was not considered worth while to carry on any systematic program of check tests during the present investigation.

The models were very carefully constructed and it is believed that the average deviation from the lines was not more than ±0.01 inch. Special care was taken to produce sharp edges at the step and chines and to avoid any small local irregularities. The models were made of white pine and covered with four coats of spar varnish rubbed down to a very smooth finish with wet sandpaper between coats. The average length of time required to construct a model was about 48 man-hours with an additional 8 man-hours for setup preparatory to testing.

TEST RESULTS

The graphical records of the test results were mounted directly on large charts, one for each set of particulars. One of these large charts, for the reference ship, has been sufficiently reduced in size to permit including it in this report and is shown as figure 5.

This type of chart is considered an important presentation of the results because it provides a complete comprehensive view of all the porpoising characteristics under a given set of particulars and not merely of the stability limits.

Description of Large Chart - One for

Each Series of Tests (fig. 5)*

(1) The ordinates are trim angles that are measured from the base line, which makes an angle of 2° with the forebody keel; the abscissas, speeds. Speed scales are given for model and ship speeds and for the speed coefficient C_V. The Stevens Tank speed numbers for the various fixed speeds at which tests were made are given at the foot of the vertical lines drawn at these speeds.

(2) The graphical records of porpoising are placed on the chart with the small cross, which indicates the steady-motion attitude, at the height of the observed trim and longitudinally to the right of the vertical speed line, on this line, or to the left of it, depending upon whether the tail damping was one-half, one, or two times the normal tail damping, respectively. Values of the tail damping are indicated at the tops of the vertical speed lines.

(3) A circle with alternate quadrants blacked indicates that a test was made but that the motion was stable.

(4) The records are placed on their sides, so that increasing heave corresponds to progression toward the left of the chart and increasing trim, progression toward the bottom. The short horizontal and vertical lines, respectively above and to the right of a record, indicate zero trim angle and zero heave from the static flotation corresponding to 140,000 pounds in the ship.

(5) Notes are given defining the ranges of trim angles within which the forebody or afterbody was observed to be "wet" or "clear."

*This description applies particularly to the larger size of these charts. In reducing, for fig. 5, certain details have been omitted.

(6) The three curves represent the free-to-trim track* for the hull in steady motion, the upper stability limit, and the lower stability limit.

(7) The stability limit is arbitrarily defined as the trim at which the total sweep in trim angle during porpoising is 2°. The limits shown are for normal tail damping and are lifted from auxiliary charts of trim sweep, as measured on the graphical records, plotted against steady-motion trim angle at constant speed.

In order to permit ready comparison of the test results, the stability limits have been taken off the large charts described above and presented in the form of summary figures, each of which shows the stability limits for all the modifications of one variable. These summary figures constitute the principal presentation in this report:

Description of Summary Figures - One for All Modifications

of Each Variable (figs. 6 to 30)

Trim angle against speed (at the top)

Included are:

Stability limits (for 2° oscillation) - solid curves cross-hatched on unstable side

Free-to-trim tracks - center-line curves

Take-off trim tracks - dashed curves

Resistance against speed (in the middle)

Free-to-trim resistances

---

*The trim track corresponding to resultant aerodynamic moments about the center of gravity equal to zero, as obtained by interpolation. It is for the hull, alone, and not for the complete airplane.

Applied moment and resistance against trim (at the bottom)

Cross plots at four fixed speeds indicated

DISCUSSION OF RESULTS

The effects of each variable or modification covered by the tests are discussed below in some detail. It is intended that reference be made, in following the discussion, to the summary figures described in the preceding section.

It has been mentioned previously that the aim in laying out the program of experiments was to change only one variable at a time, thereby isolating its effects. Naturally the program was not entirely successful in this respect; in certain cases, two or more of the variables listed were found to constitute essentially the same change from a hydrodynamic point of view. Where this is clearly the case, it is noted in the discussion.

Group I - Weight and Inertia Loadings (Chart 1)

(1) Modification of gross weight (fig. 6)

120,000 pounds		86 percent
140,000	(normal)	100
160,000		114
200,000		143

Porpoising. Increasing the gross weight moves the range of stability in the direction of higher trim angles and leaves the width of the stable range virtually unaffected. The speeds at which porpoising starts are delayed by increasing the gross weight, and the free-to-trim track is shifted to higher trim angles in the vicinity of the hump. The free-to-trim track tends to cut across the middle of the stable ranges for all gross weights.

Resistance. Not investigated (except for the normal case).

(2) Modification of moment of inertia (fig. 7)

0.816×10^6 slug-feet^2		60 percent
1.366	(normal)	100
1.716		126
2.049		150

Porpoising. Increasing the moment of inertia reduces very slightly the range of stability at low speeds. The principal consequence of increasing the moment of inertia is to increase the porpoising amplitudes under otherwise identical conditions. The porpoising frequency is reduced also, approximately in proportion to the increase in the reciprocal of the square root of the radius of gyration.

Resistance. This modification could not affect the resistance.

(3) Modification of longitudinal position of center of gravity (fig. 8)

87 inches forward of step		53.7 percent beam forward of step
70	(normal)	43.2
50		30.8

The center of gravity was shifted by altering the location of the model pivots and reballasting. Since the hydrofoil lift is applied through the model pivots, this procedure is equivalent to altering the center of gravity and the wing position simultaneously and does not introduce an additional moment due to lift.

Porpoising. Shifting the center of gravity either forward or aft has only a very slight effect on the range of stability at moderate speeds. The principal consequence of shifting the center of gravity is to shift bodily the curves of applied moment, the result being that a different moment is required to produce the same trim angle in steady motion. As would be expected, the required change in applied moment is equal to the net weight on the water times the shift of the center of gravity and the wing,

Resistance. Not investigated for the free-to-trim condition (except for the normal case).

Group II - Aerodynamic Conditions (Chart 2)

(1) Modification of wing lift Z_0 at $\tau = 5^\circ$ (fig. 9)

$4.63\ v_s^2$ pounds		67 percent
$6.95\ v_s^2$	(normal)	100
$9.27\ v_s^2$		133

Changing the wing lift was accomplished by changing the angle between the normal hydrofoil and the hull base line which simulates a change in the incidence of the wing. This left $dL/d\tau$ and dL/dw unchanged.

Porpoising. Increasing the wing lift makes the stable range appreciably wider, chiefly by lowering the lower limit at moderate speeds. The largest lift tested prevented upper-limit porpoising at high speeds. Increasing the lift lowers the free-to-trim track at moderate speeds just above the hump, so that its relation to the lower limit of stability is virtually unaffected.

Resistance. Not investigated.

(2) Modification of wing lift rate Z_θ (fig. 10)

$0.344\ v_s^2$ pounds per degree		75 percent
$0.458\ v_s^2$	(normal)	100
$0.687\ v_s^2$		150

Changing the wing lift rate was accomplished by altering the hydrofoil size. This produced a corresponding change in the value of dL/dw. The lift at $\tau = 5^\circ$ was unchanged from the normal lift in all cases. (In later tests, described below, dL/dw was changed independently.)

Porpoising. Increasing the wing lift rate has practically no effect on the stability limits at moderate speeds and decreases the range of stability very slightly at high speeds. The free-to-trim track is unaffected at moderate speeds just over the hump.

Resistance. Not investigated.

(3) Modification of vertical velocity damping Z_w (fig. 11)

$0.458\ v_s$ pound-seconds per foot	(normal)	100 percent
$0.916\ v_s$		200

By means of a specially constructed dashpot which was attached to affect only the heaving motion, the rate of change of lift with vertical velocity was doubled. This change in the apparatus is shown in the second sketch in figure 31. The tests were limited to three speeds and to normal tail damping.

Porpoising. Study of the porpoising cycles on the graphical records fails to reveal any appreciable differences when dL/dw is doubled.

Resistance. This modification could not affect the resistance.

Note. The resultant aerodynamic moment M_0 is altered in the course of each series of tests and is not properly considered an independent variable.

(4) Modification of tail moment rate M_θ (fig. 12)

$0.98\ v_s$ pound-feet per degree		71 percent
$1.37\ v_s$	(normal)	100
$2.05\ v_s$		150

Porpoising. Increasing the tail moment rate has no noticeable effect on either stability limit or on the range of stability. The largest moment rate used appreciably reduced the size of the steady-state cycles in lower-limit porpoising at high speeds, and there was also a tendency to suppress upper-limit porpoising at very high speeds.

Resistance. This modification could not affect the resistance.

(5) Modification of tail damping rate M_q (fig. 13)

0	$\times 10^4\ v_s$ pound-foot-seconds per radian		0 percent
2.02	v_s		25
4.05	v_s		50
8.10	v_s	(normal)	100
16.2	v_s		200

Porpoising. Increasing the damping due to the horizontal tail surfaces lowers the lower limit at all speeds, the amount increasing with speed from nearly zero at the speed at which lower-limit porpoising starts to a very large amount at high speeds; at a given high speed, the effect on the lower limit progressively decreases as the tail damping is increased. Increasing the tail damping has no appreciable effect on the position of the upper limit but has a tendency to delay the speed at which this type of porpoising starts. The largest damping used (twice normal) prevented upper-limit porpoising in the region of getaway speeds.

It is worth noting that, at 19 feet per second, model speed (about 70 mph ship speed), upper-limit porpoising frequently could not be suppressed with 20 times the normal tail damping and occasionally 80 times was not sufficient. In a few instances, lower-limit porpoising was not entirely suppressed with 20 times the normal damping.

Resistance. This modification could not affect the resistance.

(6) Inclusion of phase angle between $q \times M_q$, and q (fig. 14)

0° lagging (normal)
15°
25°
35°

It had been suggested that, in the full-size airplane, there might be a time lag between the pitching velocity and the pitch damping moment produced by the tail. Special tests were therefore run to investigate this matter. The phase angle was introduced by putting a small calibrated spring between the dashpot piston and its piston rod. Tests were run at approximately the three lagging phase angles shown above, at each of three speeds, and with various values of the tail damping rate.

Porpoising. The test results showed that the greatest of the lagging phase angles considered was the only one which had any noticeable effect whatever and that its only effect was to raise the lower limit very slightly at the lowest speed investigated.

In order to make as drastic a change as possible, the afterbody was removed. For these tests, the model of the forebody alone was set up with an outrigger which permitted ballasting to keep the center of gravity in the same location with respect to the forebody and to keep the moment of inertia about the center of gravity the same as for the complete hull. This outrigger was placed high enough so that, in general, it was clear of the water.

Porpoising. The tests of the forebody alone show very clearly that the lower limit is attributable to the forebody and that an upper limit does not exist when the afterbody is removed. At moderate speeds (just beyond the hump), the afterbody keeps the trim angle down and prevents lower-limit porpoising; at all higher speeds, the lower-limit porpoising is uninfluenced by the presence or absence of the afterbody.

Resistance. Removing the afterbody decreases the resistance at high speeds in the region where an afterbody would ordinarily be wetted by spray coming off the forebody. In the region of the hump, removing the afterbody allows the trim to increase and large increases of resistance result. Also, the water load otherwise carried by the afterbody must be carried by the forebody. The forebody therefore rides deeper in the water, causing an additional increase in resistance.

Remarks. These experiments suggested the concept that the forebody and the afterbody are essentially separate parts of the hull, serving different purposes, and that to a considerable extent modifications of each may be studied independently of modifications of the other.

A comparison between the characteristics of the complete hull and those of the forebody alone reveals, in particular,

(a) That the afterbody is useful only in the lower half of the speed range to take off and that its presence at higher speeds is entirely detrimental that, at rest and at "displacement" speeds, it provides flotation

that, at moderate speeds up to the hump, it controls trim and resistance and prevents lower-limit porpoising

that, at planing speeds, it is the direct cause of upper-limit porpoising and somewhat increases resistance

(b) That the forebody is entirely self-sufficient at planing speeds and needs no help from the afterbody

These indications suggest clearly that the forebody is the main hull and that the afterbody is an appendage, the function of which is to control trim (by providing nosing-down moments) until true planing of the main hull is established.

(2) Modification of afterbody angle (fig. 17)

2°	between forebody and afterbody keels	
3°		
4°		
5°		
6°		
7°		(normal)
$9\frac{1}{2}^\circ$		
12°		

The afterbody angle was increased by rotating the afterbody at the model deck and shifting it vertically so that the step height was unchanged; it was reduced by rotating the afterbody at its keel, leaving the step height unchanged.

Porpoising. Increasing the afterbody angle raises the lower limit at moderate speeds and causes it to start at a slightly lower speed but has no appreciable effect on the lower limit at high speeds; the upper limit is raised and, with the two greatest afterbody angles, the upper limit is suppressed at high speeds. Reducing the afterbody angle lowers the lower limit at moderate speeds and shifts its starting point to progressively higher speeds but again has no effect on the lower limit at very high speeds. The upper limit is lowered at all speeds and its starting point shifted to progressively higher speeds. With afterbody angles less than normal, the high-speed upper-limit porpoising becomes increasingly violent as the angle is reduced.

Resistance. The afterbody angle for optimum hump resistance appears to be about $3\frac{1}{2}^{\circ}$ for this hull; with angles greater or less than this the hump resistances are considerably increased. This is consistent with the findings of reference 6 in a general way. At very high speeds, the optimum trim and resistance are not particularly affected by afterbody angle.

(3) Modification of afterbody length (fig. 18)

2.25 times beam at main step
2.75 (normal)
3.25

The afterbody length was altered by applying a constant multiplier to the station spacing and moving the stations in or out along the afterbody keel. Thus the afterbody angle and the step height were unchanged.

Porpoising. Decreasing the afterbody length raises the upper limit slightly and has only a very small effect on the lower limit at moderate speeds just past the hump; the speed range over which the free-to-trim track passes below the lower limit is lengthened slightly. The shortest afterbody tested stopped high-speed upper-limit porpoising in the present instance. The effects are generally similar to those resulting from modifying the afterbody angle.

Resistance. Only the free-to-trim resistance was investigated in this case. Increasing the afterbody length lowers the hump resistance somewhat. The shortest afterbody used had a very high resistance peak just before the true hump, though this presumably might have been eliminated by relocating the tail cone.

(4) Modification of afterbody chine flare (fig. 19)

Chine flare removed
Normal
Extended

The normal afterbody chine flare ends abruptly, forming a partial step a little forward of the stern post. Two modifications were tried (1) extending the chine flare aft so that it washed out at the stern post (2) removing all the chine flare.

Porpoising. Extending the afterbody chine flare lowers the lower limit very slightly at moderate speeds and leaves the upper limit practically unaffected. Removing the afterbody chine flare raises the lower limit slightly at speeds just beyond the hump and raises the upper limit slightly, and prevented high-speed upper-limit porpoising in the present tests.

Resistance. Removing the afterbody chine flare causes a high peak in the resistance before the true hump and slightly increases the true hump. The very high peak appeared to result from water clinging to the afterbody sides and running up the tail cone. Removing the afterbody chine flare had almost no effect at high speeds. Resistance tests were not run with the afterbody chine flare extended.

(5) Modification of height of main step - first series (fig. 20)

1 percent of beam
3
5 (normal)
7

The step height was altered in this series by shifting the entire afterbody vertically with respect to the forebody.

Porpoising. Increasing the step height in this way raises the lower limit at moderate speeds just past the hump but has no appreciable effect at higher speeds. The upper limit is raised at all speeds and upper-limit porpoising at very high speeds is suppressed. When the step height is decreased, the violence of the high-speed upper-limit porpoising is progressively increased until, with the lowest height tried, this type of porpoising is exceptionally violent in the region of get-away.

Resistance. Only free-to-trim resistance was investigated. Increasing the step height slightly increases the hump resistance and reduces the high-speed resistance. These indications are consistent with those found in reference 7.

(6) Modification of height of main step - second series (fig. 21)

1 percent of beam
5 (normal)
9
13

The step height was altered in this series by rotating the afterbody about the intersection of the afterbody keel and the stern post in the normal hull. Thus the position of the stern post was unaltered. The tests were carried to a greater maximum step height than in the first series.

Porpoising. Increasing the step height in this way has practically no effect on the lower-limit at any speed or on the position of the upper limit. The step heights greater than normal again suppressed the high-speed upper-limit porpoising and the 1 percent step height gave exceptionally violent high-speed upper-limit porpoising.

The position of the free-to-trim track just past the hump is not affected when the step height is altered in this way.

Resistance. Increasing the step height has practically no effect on the true hump but decreases the peak before the true hump. At very high speeds the resistance appears to be slightly decreased by increasing the step height to greater than normal.

(7) Modifications of afterbody dead rise at stern post - no chine flare (fig. 22)

-10° dead rise at afterbody stern post
0°
10°
20° (normal)
30°

The afterbody was warped by leaving the dead rise at the main step unchanged and altering the dead rise at the stern post; the buttocks were kept straight lines. The step height and the angle of the afterbody keel were unaltered. No afterbody chine flare was used.

Porpoising. Decreasing the afterbody stern-post dead rise has practically no effect on the lower limit at any speed but lowers the upper-limit at all speeds. Possibly because of the absence of afterbody chine flare, the high-speed upper-limit porpoising was suppressed in all cases. The stern-post dead rise which causes the greatest suppression of the high-speed upper-limit porpoising was found to be about 10°. From the standpoint of upper-limit porpoising, stern-post dead-rise angles between 10° and 20° appear to give the best all-round results.

Resistance. Decreasing the afterbody dead rise at the stern post causes an appreciable decrease of the discontinuity that appears before the hump. The true hump resistance is also lowered but to a much lesser extent. At very high speeds, the resistance is not altered materially, but 10° dead rise appears to be about the best angle.

(8) Ventilation of main step for step height of 1 percent - rough preliminary trial (fig. 23)

$\left.\begin{array}{l}\text{No ventilation}\\ \text{Ventilation}\end{array}\right\}$ Step height 1 percent beam

Ventilation of the main step was accomplished by shifting the afterbody (set for 1 percent step height) aftward along its keel by 5 percent of the beam and leaving open the gap thus caused. The afterbody angle remained unchanged from the normal. The tests are looked upon as very preliminary in nature.

Porpoising. Ventilating the main step in this way raises the upper limit slightly and entirely suppresses high-speed upper-limit porpoising. The lower limit was not investigated.

The effect of this ventilation, even though impossible to construct from a practical viewpoint, is remarkable in that it suppressed entirely the very violent high-speed upper-limit porpoising (the most violent yet encountered) which occurred with an unventilated 1 percent step.

Resistance. Not investigated.

Group IIIF - Forebody Form (Chart 3)

Drawings of modifications are shown in figure 33. The manner in which the various modifications were carried out should be especially noted.

(1) Modification of forebody form - first series of warping (fig. 24)

Constant section (minimum warping)
Normal forebody
Linear dead-rise variation (maximum warping, dead rise changes 9.7° per beam forward of step)

The first forebody in this group had the same length as the normal forebody, but all the sections of the normal forebody were compressed into the forward half. The after half had the uniform section found at the main step in the normal hull.

The third model was constructed with a linear variation of dead rise from the forepoint to the main step. The step section, the profile, the chine plan form, and the dead rise near the forepoint were unaltered.

Both models were tested with the normal afterbody. These models may be considered as belonging to a group in which warping of the forebody bottom near the step is the variable, the change of warping being small between the first and the normal models and large between the normal and the third models.

Porpoising. Increased warping of the forebody bottom lowers the lower limit very materially at all except the very lowest speeds and very slightly lowers the upper limit at all speeds. At hump speeds, increasing the warping of the forebody bottom has no great influence on the free-to-trim track but lowers it materially at higher speeds.

Resistance. Increasing the forebody warping increases the hump resistance appreciably, and also increases the resistance at high speeds when the afterbody is clear. This is consistent with the findings of reference 8.

(2) Modification of forebody warping - second series (fig. 25)

Dead-rise changes 0° per beam forward of step
2.7°
5.4°
8.1°
10.8°

The forebody warping in each case was linear from step to forepoint in exactly the same manner as in the linear-dead-rise-variation model referred to above. This resulted in having very low dead rise in the forward half of the forebody in most cases. The series was built to explore the effect of forebody warping more systematically than in the first series.

Porpoising. Increasing the warping of the forebody bottom very appreciably lowers the lower limit at high speeds but only slightly at speeds just beyond the hump. The upper limit is also lowered, but to a very much less extent. Increasing the warping of the forebody lowers the free-to-trim track at high speeds. These effects are similar to those found in the first series.

It was found that the two models with a dead-rise change of 0° per beam and 2.7° per beam had noticeable tendencies toward diving at very high speeds and low trim angles. This is undoubtedly due to the bow sections having insufficient dead rise and is of little interest here.

<u>Resistance</u>. Increasing the forebody warping increases the resistance, at both the hump and planing speeds.

(3) Modification of forebody length (fig. 26)

2.82 times beam at main step	
3.44	(normal)
4.07	

The models in this group all used the same forebody sections; the alteration consisted of applying a constant multiplier to the station spacing. The stations were shifted in or out parallel to a line tangent to the normal forebody keel at the step. The multipliers for station spacing were the same as for the modifications of afterbody length (group IIIA, chart 3).

In the planing range, the alterations in this group may be considered as constituting small changes in the warping of the forebody.

<u>Porpoising</u>. Decreasing the forebody length slightly lowers both the lower and upper limits. With the shortest forebody, the hull swamped at speeds below the hump; no difficulty was found at high speeds, however, when steps were taken to support the model while it passed over the hump.

<u>Resistance</u>. Decreasing the forebody length increases the hump resistance appreciably and the resistance at planing speeds slightly.

If the alterations are considered as changes of forebody warping near the step, then the trends in resistance and porpoising are the same as for the two preceding series.

Group IIIH - Hull Form (As a Whole)(Chart 3)

Drawings of modifications are shown in figure 33. The manner in which the various modifications were carried out should be especially noted.

(1) Modification of hull length (fig. 27)

5.07 times beam at main step
6.19 (normal)
7.32

The hull length was altered by joining the altered-length forebodies (group IIIF) to the similarly altered afterbodies (group IIIA). The step height and the afterbody angle remained unaltered.

Porpoising. Increasing the hull length lowers the lower limit very slightly at low speeds and raises it slightly at higher speeds; the upper limit is lowered very slightly. The free-to-trim track in the region just past the hump, where it is important, is virtually unaltered.

Resistance. Increasing the hull length very appreciably reduces the hump resistance. At planing speeds, the resistance is very slightly reduced. These effects are consistent with those mentioned in reference 8.

(2) Modification of hull dead rise (fig. 28)

0.5 times normal dead rise at each station (10° at step)
1.0 (20°)(normal)
1.5 (30°)

The hull dead rise was altered by multiplying the dead rise at each station by the same constant. The keel profile was unaltered, but the chines were changed as necessary. The chine flares were increased in proportion to the dead rise.

Porpoising. Increasing the hull dead rise raises the lower limit quite materially and lowers the upper limit somewhat. The speeds at which both the upper and the lower limits start are progressively increased with increasing hull dead rise.

In the vicinity of 14 feet per second, model speed (about 55 mph for the ship), the upper and lower limits almost come together when the hull dead rise is 10°. Thus it would be nearly impossible for such a hull to take off without passing through a region of instability. When the dead rise is 30°, there is only a small gap between the upper and lower limits at speeds near get-away.

Resistance. Increasing the hull dead rise increases the resistance appreciably at all planing speeds. The true hump resistance is not greatly affected but is least with 20° hull dead rise. With both 10° and 30° dead rise, the afterbody chine flare appeared insufficient to prevent considerable side and tail-cone wetting at low speeds and, thus, a large resistance peak before the true hump. These findings are in general agreement with those in reference 6.

Spray. No measurements were made of volume or height of the spray, but increasing the hull dead rise appeared to lower the height of the spray and to make the hull much cleaner running.

(3) Modification of longitudinal step position (fig. 20)

541 inches aft of forepoint	(shifted 10.5 percent beam forward)
558	(normal)
578	(shifted 12.4 percent beam aft)

The longitudinal position of the main step was altered by extending or chopping off the original forebody and altering the afterbody length in the opposite sense. The step height, the angle between the afterbody keel and base line, and the longitudinal location of the stern post were kept unaltered.

The net result is that of combining several of the modifications already considered. When the step is moved forward, the forebody is shortened and its warping very slightly increased, the afterbody is lengthened, and the afterbody angle is in effect slightly reduced; also, the center of gravity is farther aft relative to the step.

This modification was included mainly because shifting the step is a relatively simple change to carry out in full size.

Porpoising. Moving the main step forward lowers the lower limit very slightly at all speeds, as might be expected from the slightly increased warping of the forebody bottom. The upper limit is slightly lowered at all speeds, again as might be expected from the decreased equivalent afterbody angle.

Moving the main step forward has substantially the same effect on the moment curves as shifting the center of gravity aft by the same amount. The shift of the moment curves is equal to the weight on the water times the distance the step is moved.

Resistance. Not investigated.

(4) Modification of plan form of main step (fig. 30)

45° swallow tail
Transverse (normal)
45° V

The plan form of the main step was altered without changing the keel lines of either the forebody or the afterbody. The amount of planing area shifted aft of the normal transverse step was balanced by removing an equal area forward of the normal transverse step. This left unaltered the "mean" transverse step and step height.

Porpoising. In going from a swallow-tail step to a V-step, the position of the upper limit is raised appreciably and the intensity of the upper-limit porpoising, increased. At moderate speeds the V-step lowers the lower limit, and the swallow tail raises it. The situation is reversed at high speeds but the effects are not so marked.

Resistance. The plan form of the main step does not have any appreciable influence on the true hump resistance (reference 9). The V-step, however, decreases the height of the peak in the resistance curve before the true hump. At high speeds, the V-step appears to have highest resistance and the swallow tail the lowest resistance in the region in which the afterbody is wetted.

T.N 538

COMMENTS ON THE TESTS

In a broad sense, lower-limit porpoising and upper-limit porpoising are distinguished, beyond the difference in the general region of trim angles in which each occurs, by the differing character of the porpoising motions.

Lower-limit porpoising is largely a phenomenon of the forebody alone, while upper-limit porpoising depends upon both the forebody and the afterbody and their relation to each other. In lower-limit porpoising, the motion is smooth and regular and the afterbody is, in general, clear of the water. In upper-limit porpoising, the motion is very irregular, though consistent in successive cycles in a given case, and the hull appears to be thrown back and forth, the forebody and afterbody alternately carrying the bulk of the water load; the motion tends to have large amplitudes in heave and relatively small amplitudes in pitch.

By referring to the chart in figure 5, which shows the graphical records of porpoising for the normal airplane, it is apparent at once that the amplitude of lower-limit porpoising is relatively insensitive to changes to trim angle and damping rate at speeds near the hump but that it becomes increasingly sensitive to both as the speed increases and is extremely sensitive at high speeds. This means, in effect, that from a practical point of view lower-limit porpoising is much more dangerous at high speeds than at low.

Upper-limit porpoising starts at higher speeds than lower-limit porpoising. It develops very suddenly as the trim angle exceeds that at which the afterbody takes an appreciable fraction of the load, though a large change of moment is ordinarily required to bring this about. The droop of the upper-limit curves with increase of speed appears to be caused by progressive changes in the shape of the roach left by the forebody. As opposed to lower-limit porpoising, the amplitude of upper-limit porpoising is ordinarily quite insensitive to changes of damping rate and to the speed; the motion is essentially violent at all times. The speed range over which it occurs can often be slightly reduced at its ends by increased tail damping; at speeds in the middle of the range, however, increasing the damping rate to 80 times normal quite frequently has little effect.

A few special tests were made under the normal particulars to explore the range in trim angle of upper-limit porpoising. The indication that upper-limit porpoising was encountered when, with increasing trim angle, the afterbody would have taken an appreciable fraction of the total load if the motion had remained steady suggested that this type of porpoising might be eliminated and stability reestablished if the bulk of the load were transferred to the afterbody. This was found to be the case. Very large stalling moments - far beyond any magnitudes possible in practice - were required, as had been anticipated, and the return to stable motion usually occurred only when the forebody came clear - the entire load then being supported by the afterbody. What had not been anticipated is the fact that the trim angle under these conditions can be less than that of the ordinary upper-limit curve.

CONCLUSIONS

Group I - Weight and Inertia Loadings

1. Increasing the gross load raises the trim angles at which both the upper and lower limits of stability occur and delays their starting to higher speeds.

2. Neither moment of inertia in pitch nor the center-of-gravity position has any appreciable influence on the limits of stability, though the latter has a pronounced effect on the moments and thus on the available trim range.

Group II - Aerodynamic Conditions

1. The actual lift at arbitrary trim Z_o and the rate of change of lift with trim Z_θ are the only aerodynamic variables which influence the position of both limits. It will be noted that these two variables, in contradistinction to any other aerodynamic variables, affect the net load on the water in steady motion.

2. The aerodynamic pitch damping rate M_q has a large effect on the lower limit of stability at high speeds, but its effect decreases as the damping is increased and is much less at damping rates near normal than at lower damping rates. The damping rate has practically no effect on the upper limit of stability.

3. None of the other aerodynamic derivatives has appreciable effects on either stability limit.

Group IIIA - Afterbody Form

1. Modifications which raise the stern post have the following general effects:

(a) To raise the upper limit and, if carried far enough, to suppress upper-limit porpoising at high speeds

(b) To raise the lower limit in the vicinity of the hump

(c) To raise the free-to-trim track in the vicinity of the hump and the hump resistance

They do not affect the lower limit at high speeds.

2. High-speed upper-limit porpoising was suppressed in the present tests by increasing the step height, by ventilating the step, or by removing the afterbody chine flare. This point needs further investigation.

Group IIIF - Forebody Form

1. Modifications which increase the warping of the forebody bottom lower the lower limit of stability very appreciably and the upper limit very slightly.

Group IIIH - Hull Form (As a Whole)

1. Increasing the hull dead rise raises the lower limit appreciably and lowers the upper limit moderately.

2. The step position has very little influence on the stability limits, its chief effect being to shift the moment curves, as in the case of a center-of-gravity shift.

3. Changes of hull length have the combined effects of independent changes of forebody and afterbody length.

4. A swallow-tail step has less intense high-speed upper-limit porpoising than a normal transverse step, but the usual step has on the whole better stability characteristics than either the V- or swallow-tail steps.

Experimental Towing Tank,
Stevens Institute of Technology,
Hoboken, N. J.

REFERENCES

1. Perring, W. G. A., and Glauert, H.: Stability on the Water of a Seaplane in the Planing Condition. R. & M. No. 1493, British A.R.C., 1933.

2. Klemin, Alexander, Pierson, John D., and Storer, Edmund M.: An Introduction to Seaplane Porpoising. Jour. Aero. Sci., vol. 6, no. 8, June 1939, pp. 311-318.

3. Coombes, L. P., Perring, W. G. A., and Johnston, L.: The Use of Dynamically Similar Models for Determining the Porpoising Characteristics of Seaplanes. R. & M. No. 1718, British A.R.C., 1935.

4. Olson, Roland E., and Land, Norman S.: The Longitudinal Stability of Flying Boats as Determined by Tests of Models in the NACA Tank. I - Methods Used for the Investigation of Longitudinal-Stability Characteristics. NACA A.R.R., Nov. 1942.

5. Murray, A. B.: Stevens Institute Opens Experimental Model Towing Tank. Marine Engineering and Shipping Age, vol. 40, no. 8, Aug. 1935, pp. 300-304.

6. Bell, Joe W., and Willis, John M., Jr.: The Effects of Angle of Dead Rise and Angle of Afterbody Keel on the Resistance of a Model of a Flying-Boat Hull. NACA A.R.R., Feb. 1943.

7. Bell, Joe W.: The Effect of Depth of Step on the Water Performance of a Flying-Boat Hull Model - N.A.C.A. Model 11-C. T.N. No. 535, NACA, 1935.

8. Shoemaker, James M., and Parkinson, John B.: Tank Tests of a Family of Flying-Boat Hulls. T.N. No. 491, NACA, 1934.

9. Dawson, John R.: A General Tank Test of N.A.C.A. Model 11-C Flying-Boat Hull, Including the Effect of Changing the Plan Form of the Step. T.N. No. 538, NACA, 1935.

TABLE I

DIMENSIONS AND PARTICULARS (NORMAL) FOR FULL-SIZE

FLYING BOAT XPB2M-1 AND $\frac{1}{30}$-SCALE MODEL

Dimensions	Full size	1/30-scale model
Beam at main step, in	162	5.40
[a]Angle between forebody keel and base line, deg	2.0	2.0
Angle between afterbody keel and base line, deg	5.0	5.0
Height of main step at keel, in	8.1	0.27
Center of gravity forward of main step (26.58 percent M.A.C.), in	70	2.33
Center of gravity above base line, in	146.7	4.89
Gross weight, Δ, lb	140,000	5.19 f.w.
Load coefficient, C_Δ (sea water)	0.89	
Moment of inertia in pitch, slug-ft^2	1.366×10^6	
lb-in^2	6.328×10^9	260
Wing span, ft	200	6.67
Wing area, S, sq ft	3683	4.092
Mean aerodynamic chord, M.A.C., in	249	8.30
Aspect ratio (geometric)	10.87	10.87
Horizontal tail area, sq ft	508	0.565
Elevator area, sq ft	143.7	0.160
Distance c.g. to 35 percent M.A.C. horizontal tail (tail length), ft	63.6	2.12
Thrust line above base line at main step, in	230.3	7.68
Thrust line inclined upward to base line, deg	5.5	5.5

Ratios $\frac{\text{Full-size}}{\text{Model}}$

Of velocities, $\lambda^{1/2}$	5.477
Of linear dimensions, λ	3.0×10
Of areas, λ^2	9.0×10^2
Of volumes, λ^3	27.0×10^3
Of moments, λ^4	81.0×10^4
Of moments of inertia, λ^5	243.0×10^5

[a]See footnote on p.40.

TABLE I

DIMENSIONS AND PARTICULARS (NORMAL) FOR FULL-SIZE FLYING

BOAT XPB2M-1 AND $\frac{1}{30}$-SCALE MODEL (Continued)

Aerodynamic characteristics	Full size	1/30-scale model
C_L at $\tau = 5^\circ$ (relative to base line, flaps, 30°)	1.585	1.585
L at $\tau = 5^\circ$	$6.95\ v_{s}^{2}$[c]	$7.72 \times 10^{-3}\ v^2$
$dC_L/d\tau$	0.1045	0.1045
$dL/d\tau$ $(dZ/d\theta)$, lb/deg	$0.458\ v_s^2$	$0.509 \times 10^{-3}\ v^2$
dL/dw (dZ/dw), lb-sec/ft $\left(\frac{dL}{d\tau}\frac{1}{v}\right)$	$0.458\ v_s$	$0.509 \times 10^{-3}\ v$
$dC_{M_{CG}}/d\alpha_{BL} = dC_{M_{CG}}/d\tau$ (av.)	0.0150	0.0150
$dM\ /d\tau$ $(dM/d\theta)$, lb ft/deg (av.) . . .	$1.365\ v_s^2$	$5.05 \times 10^{-5}\ v^2$
[b]dM/dq, lb ft sec/radian	$8020 \times v_s$	$9.90 \times 10^{-3}\ v$
dM/dw, lb sec (av.)	$78.3 \times v_s$	$2.90 \times 10^{-3}\ v$
$\frac{dM/dq}{dM/dw}$, ft/radian	102.5	3.41
$\frac{dM/dq}{dM/dw}$ /Tail length, 1/radian	1.61	1.61
Get-away speed, fps	130	23.74
Get-away C_L	1.890	1.890
Get-away τ, deg	8.8	8.8

[a]All trim angles measured relative to the base line.
[b]Contribution of horizontal tail surface only.
[c]Subscript s is for full size.

RADIATING CHART OF VARIABLES

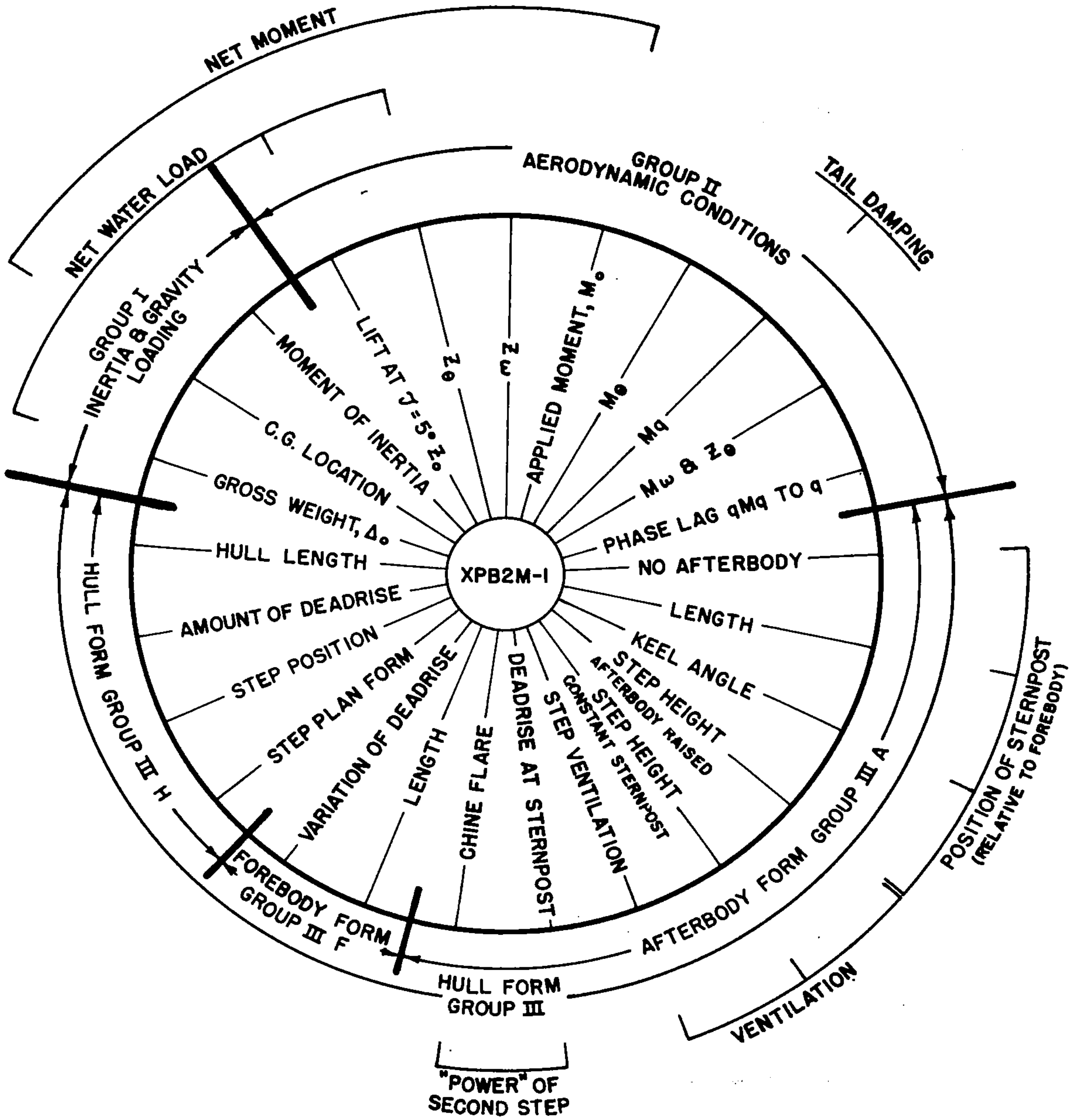
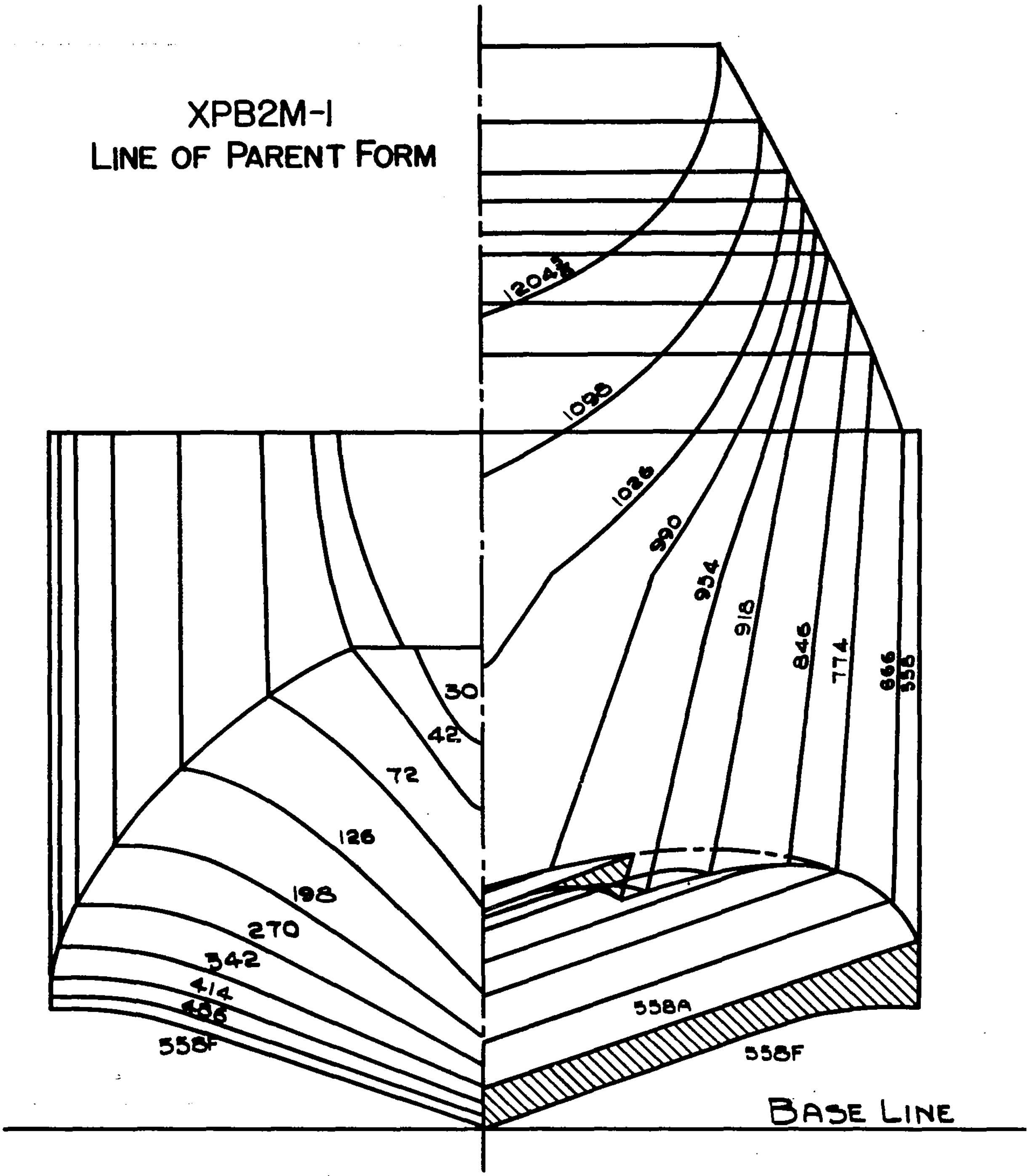
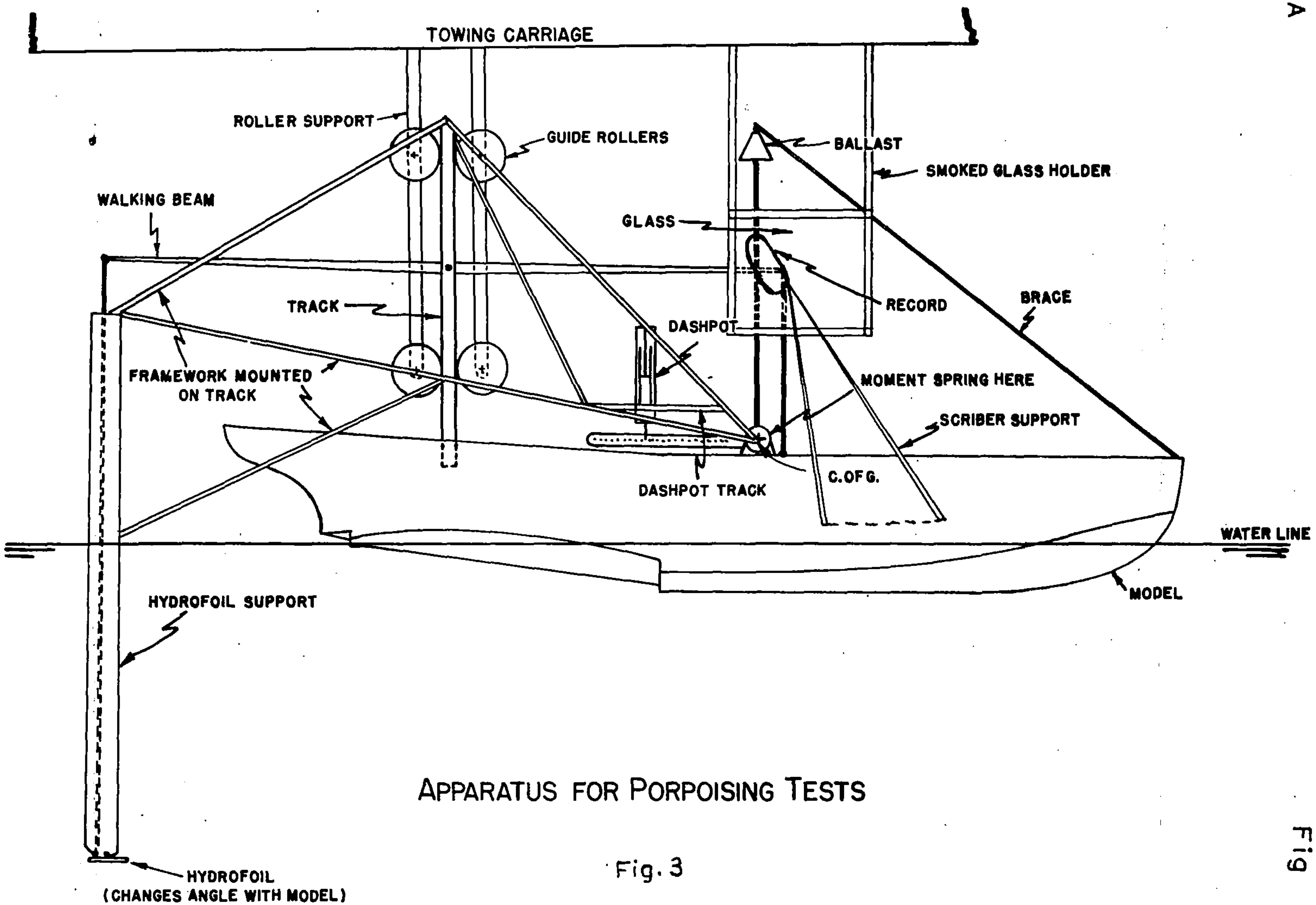


Fig. 1



Station Numbers are Inches Aft of Forepoint on Full Size.

Fig. 2



APPARATUS FOR PORPOISING TESTS

Fig. 3

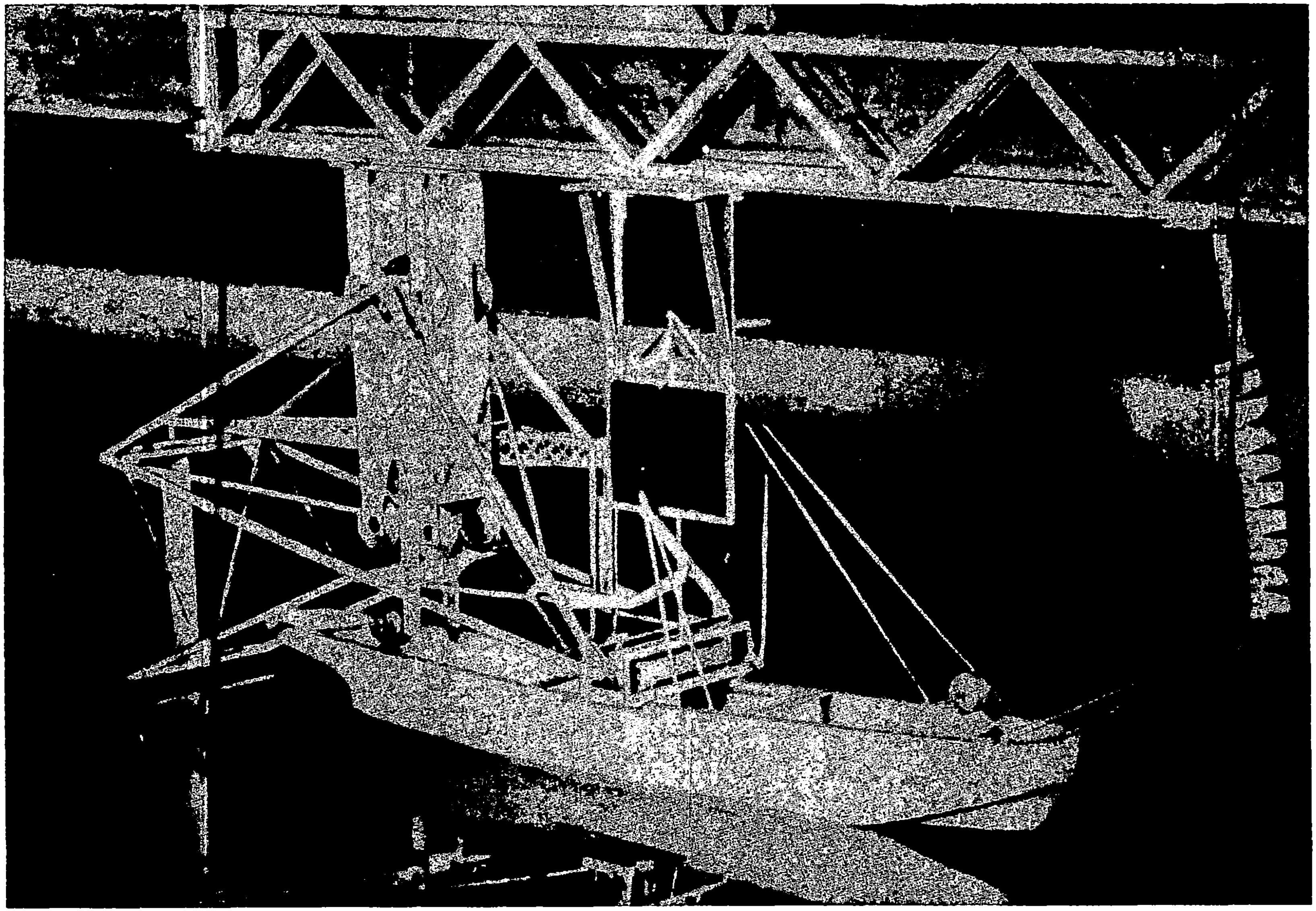


Figure 4. Apparatus for porpoising test.

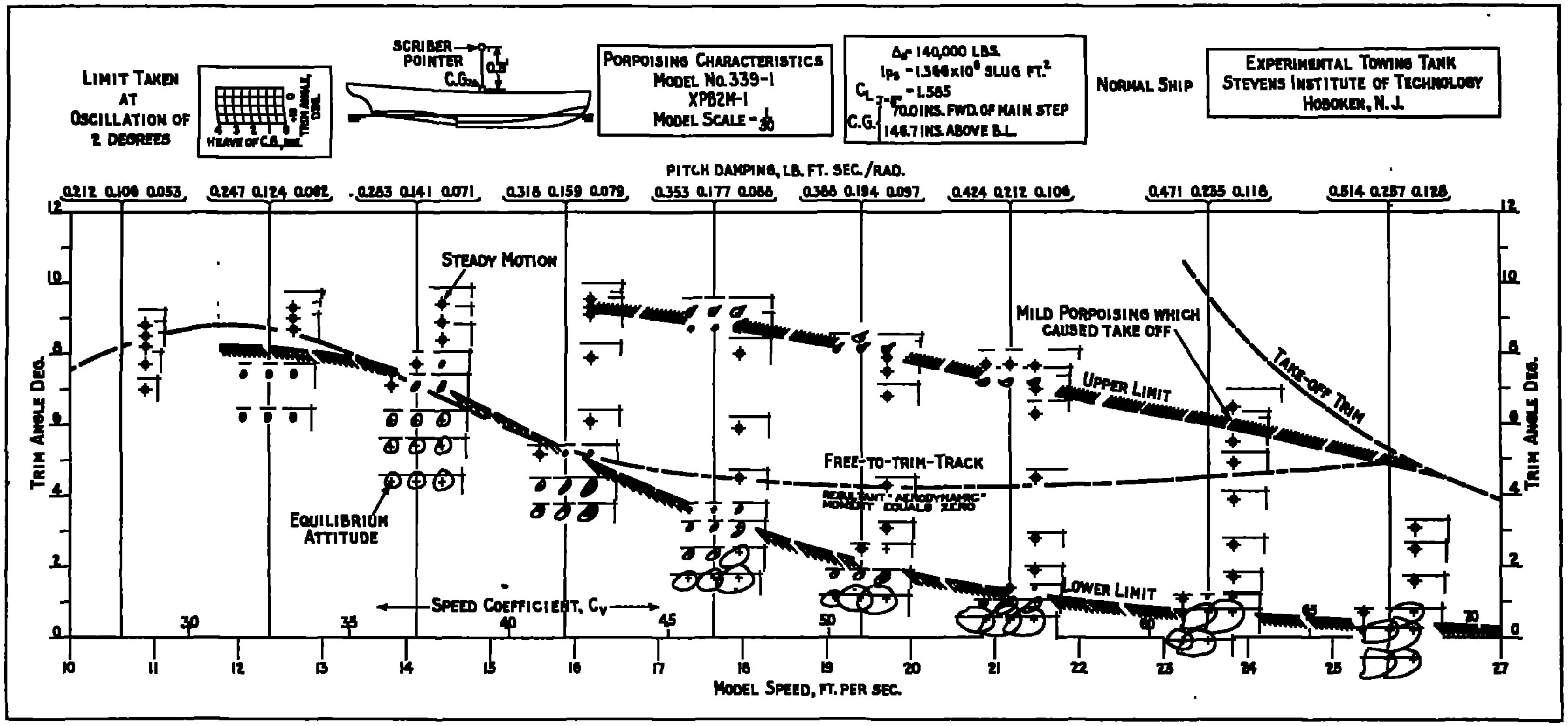
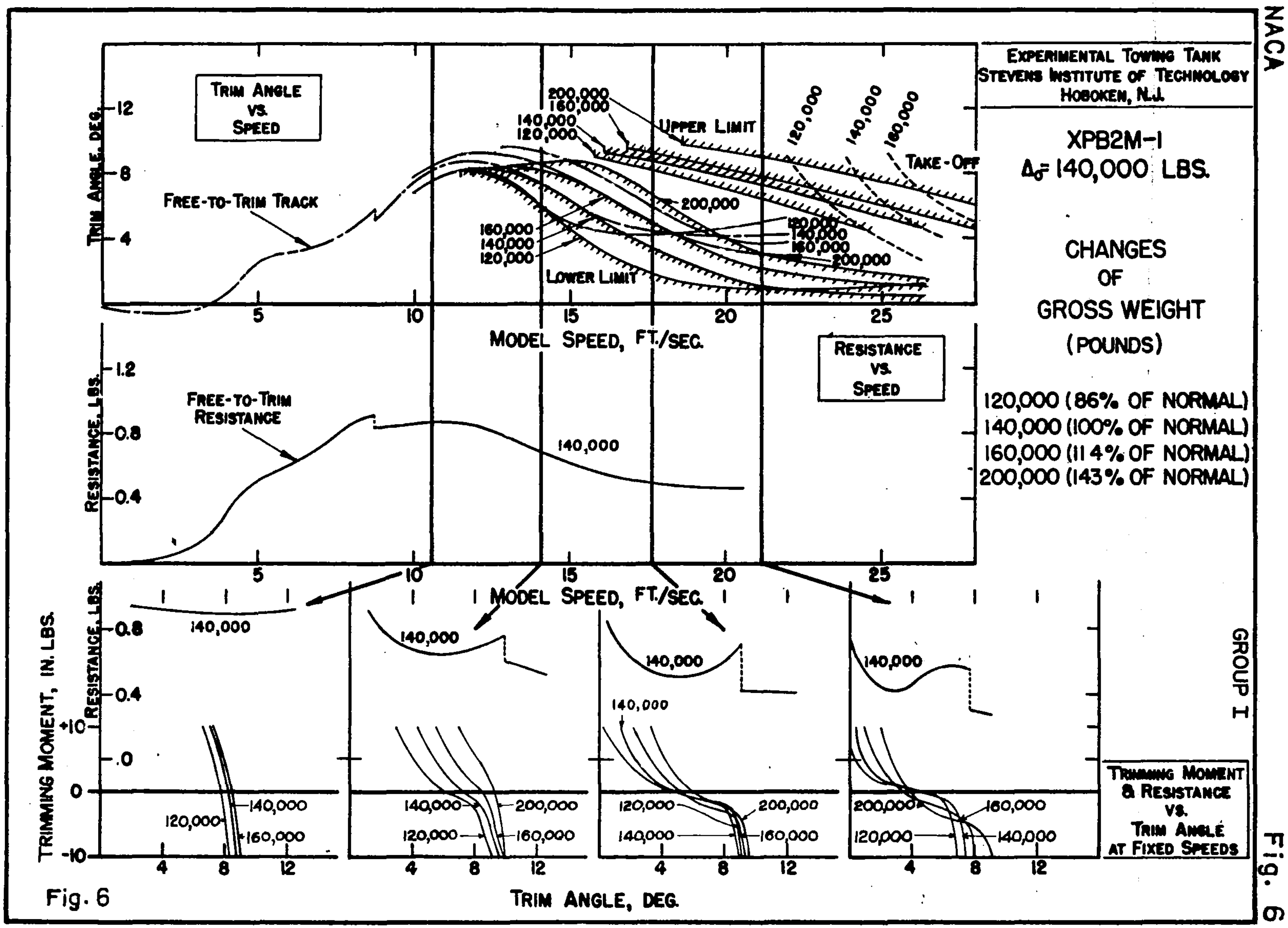
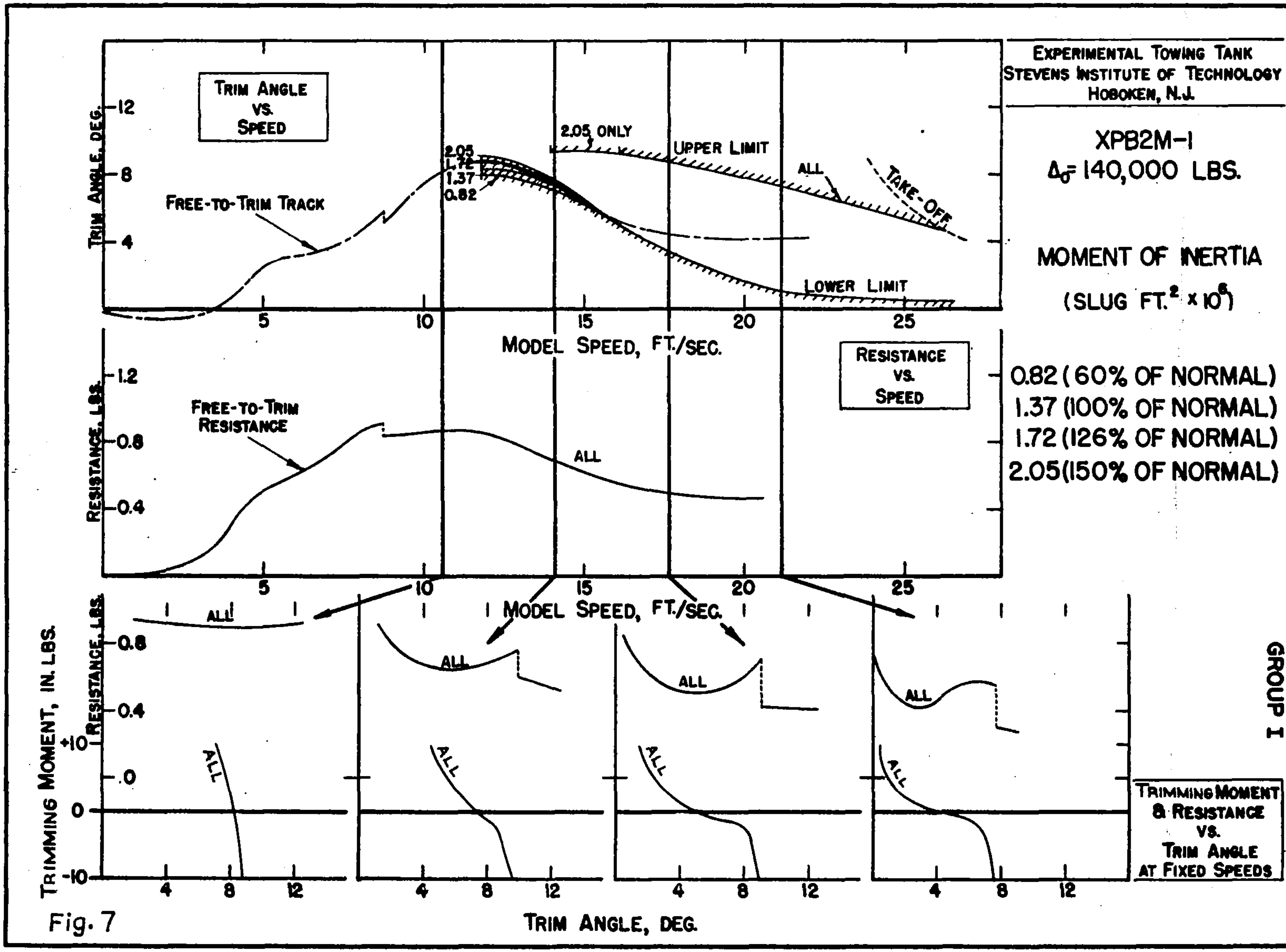


Figure 5. - Stability limits and free-to-trim track for the parent model, showing the graphical records of the porpoising cycles.



EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0 = 140,000 LBS.
CHANGES OF GROSS WEIGHT (POUNDS)
120,000 (86% OF NORMAL)
140,000 (100% OF NORMAL)
160,000 (114% OF NORMAL)
200,000 (143% OF NORMAL)
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
UPPER LIMIT
LOWER LIMIT
TAKE-OFF
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
TRIMMING MOMENT, IN. LBS.
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
TRIM ANGLE, DEG.
GROUP I
NACA

Fig. 6



EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0 = 140,000 LBS.
MOMENT OF INERTIA
(SLUG FT.^{2} x 10^6)
0.82 (60% OF NORMAL)
1.37 (100% OF NORMAL)
1.72 (126% OF NORMAL)
2.05 (150% OF NORMAL)
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
2.05 ONLY
UPPER LIMIT
ALL
TAKE-OFF
LOWER LIMIT
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
TRIMMING MOMENT, IN. LBS.
TRIM ANGLE, DEG.
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
GROUP I
NACA

Fig. 7

Fig. 7

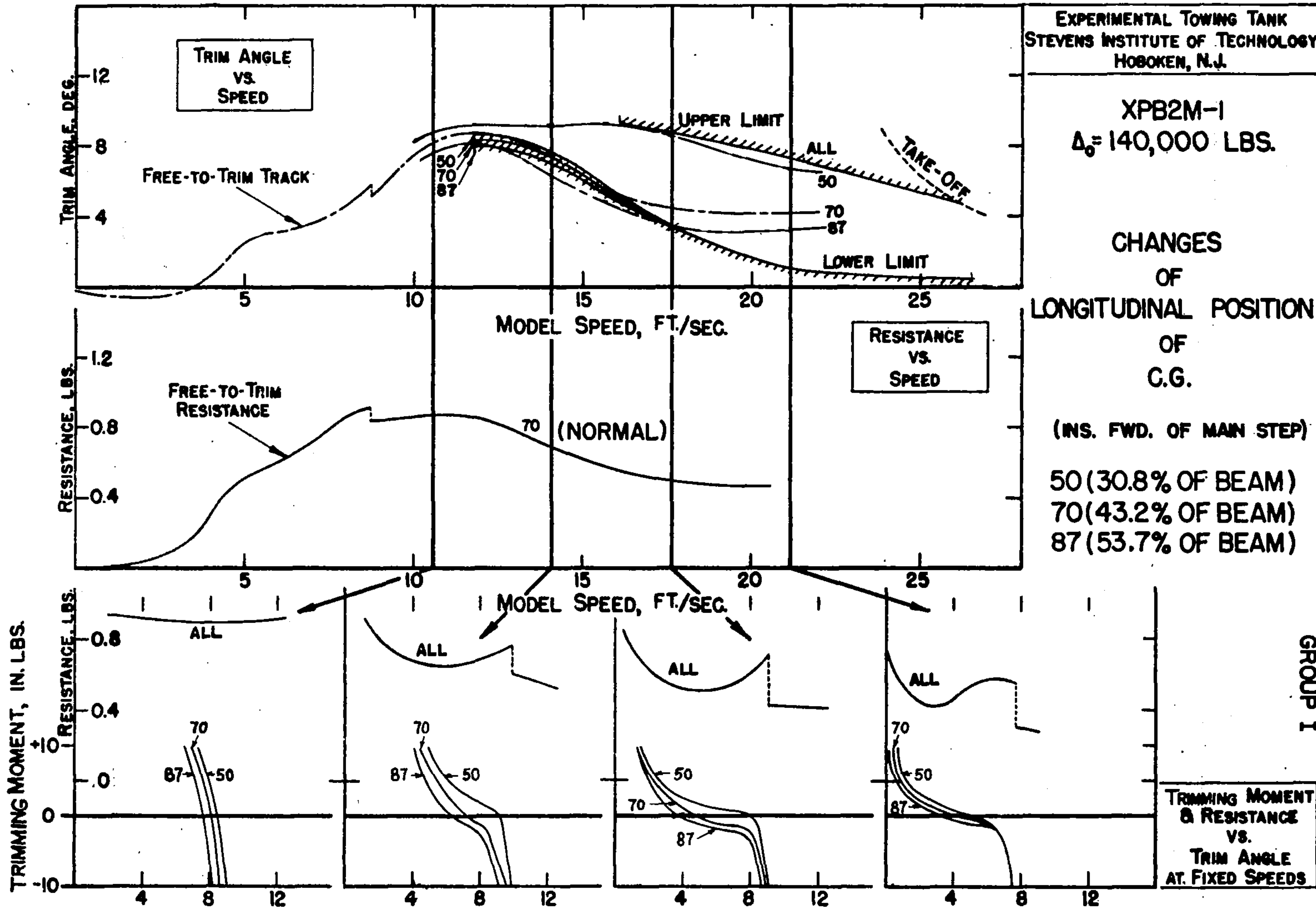


Fig. 8

NACA

Fig. 8

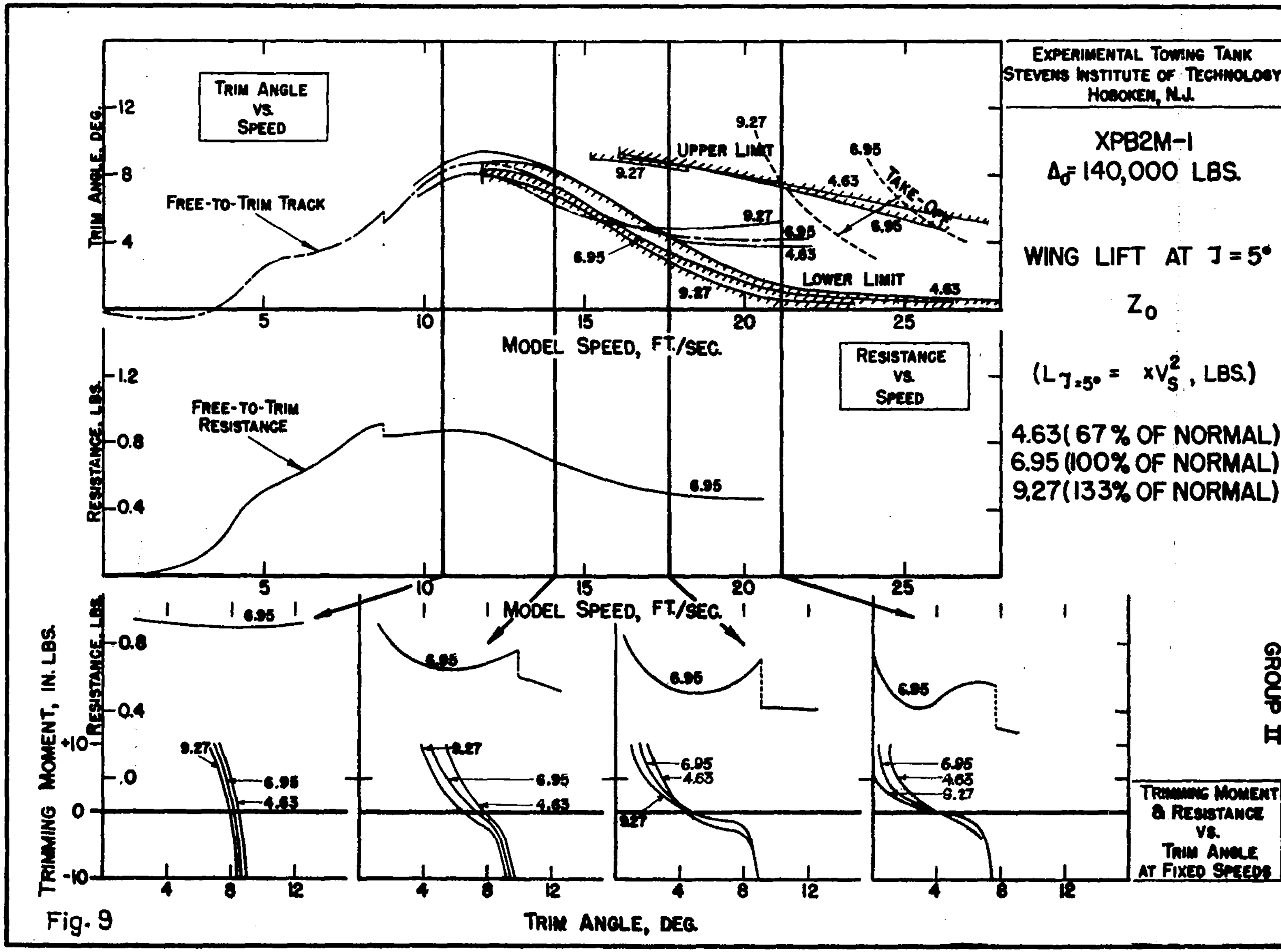

EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0 = 140,000 LBS.
WING LIFT AT $\tau = 5°$
Z_0
($L_{\tau=5°} = xV_S^2$, LBS.)
4.63 (67% OF NORMAL)
6.95 (100% OF NORMAL)
9.27 (133% OF NORMAL)
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
UPPER LIMIT
LOWER LIMIT
TAKE-OFF
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
TRIMMING MOMENT, IN. LBS.
TRIM ANGLE, DEG.
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
GROUP II

Fig. 9

Fig. 9

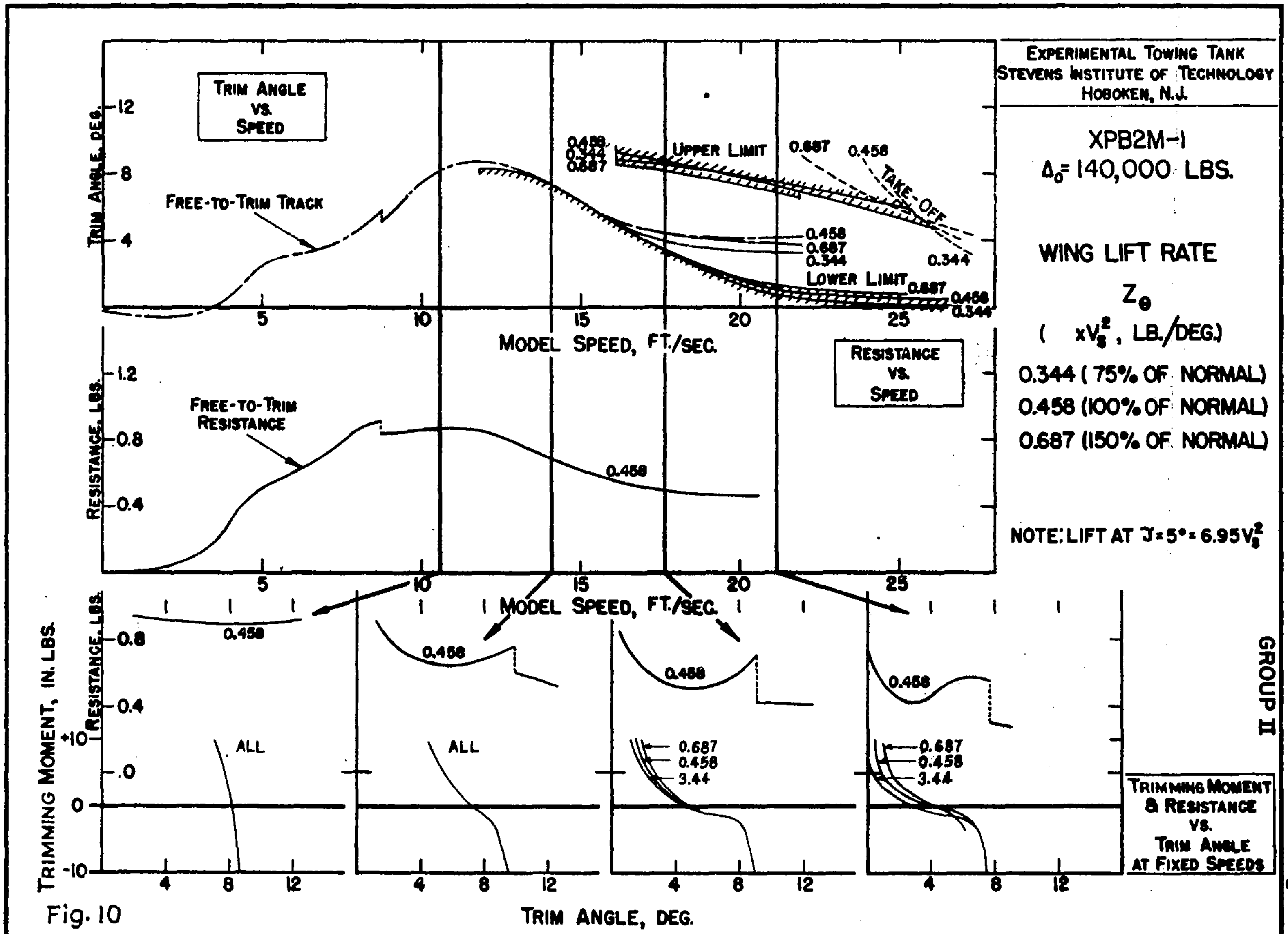
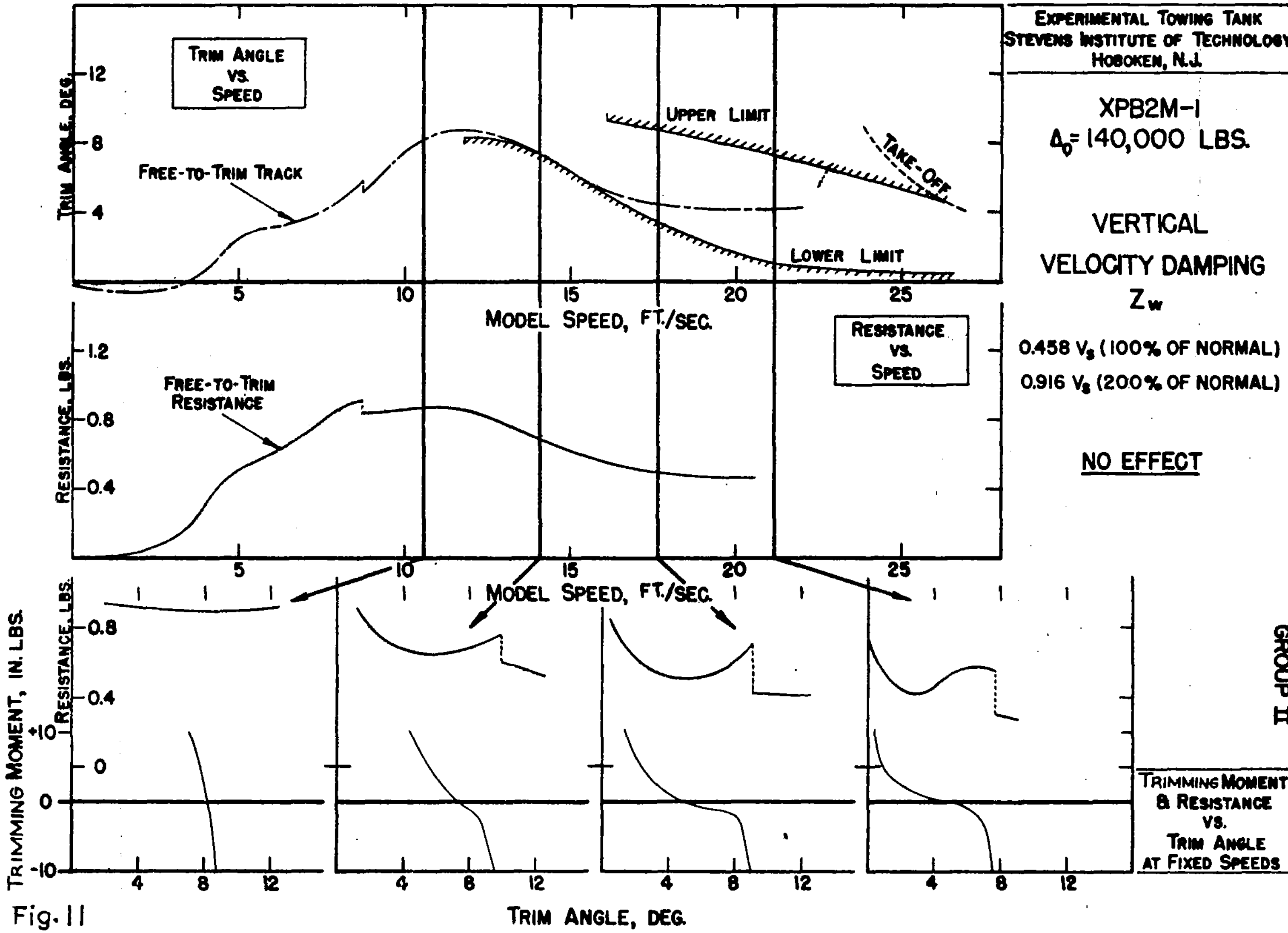

EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0 = 140,000 LBS.
WING LIFT RATE
Z_θ
(xV_s^2, LB./DEG.)
0.344 (75% OF NORMAL)
0.458 (100% OF NORMAL)
0.687 (150% OF NORMAL)
NOTE: LIFT AT τ = 5° = 6.95V_s^2
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
UPPER LIMIT
LOWER LIMIT
TAKE-OFF
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
TRIMMING MOMENT, IN. LBS.
ALL
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
TRIM ANGLE, DEG.
GROUP II

Fig. 10



EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.

XPB2M-1

Δ_0 = 140,000 LBS.

VERTICAL VELOCITY DAMPING

Z_w

0.458 V_s (100% OF NORMAL)

0.916 V_s (200% OF NORMAL)

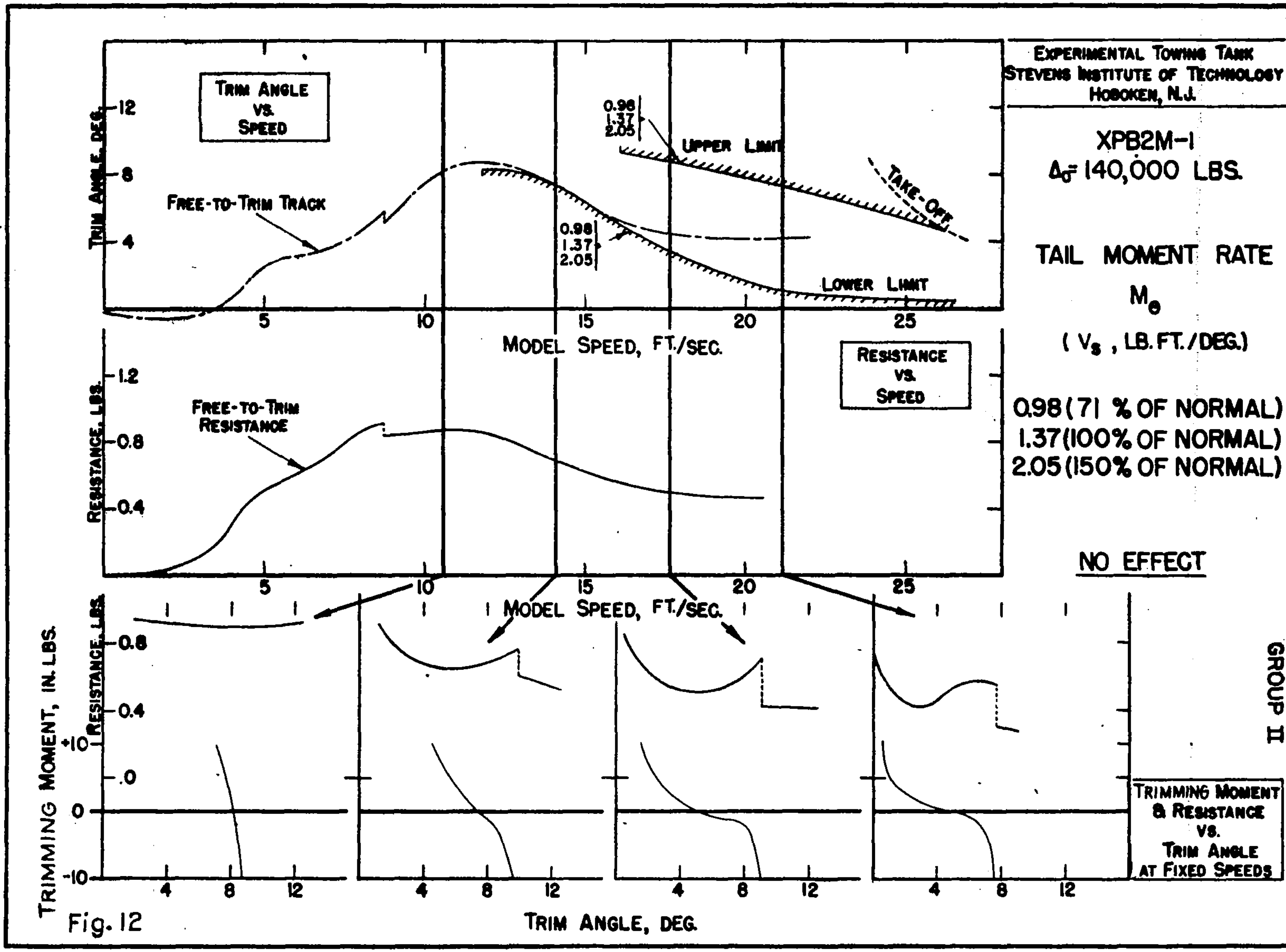
NO EFFECT

Fig. 11

NACA

GROUP II

Fig. 11



EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0 = 140,000 LBS.
TAIL MOMENT RATE
M_θ
(V_s , LB.FT./DEG.)
0.98 (71 % OF NORMAL)
1.37 (100% OF NORMAL)
2.05 (150% OF NORMAL)
NO EFFECT
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
UPPER LIMIT
LOWER LIMIT
TAKE-OFF
0.98
1.37
2.05
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
TRIMMING MOMENT, IN. LBS.
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
TRIM ANGLE, DEG.
GROUP II
NACA

Fig. 12

Fig. 12

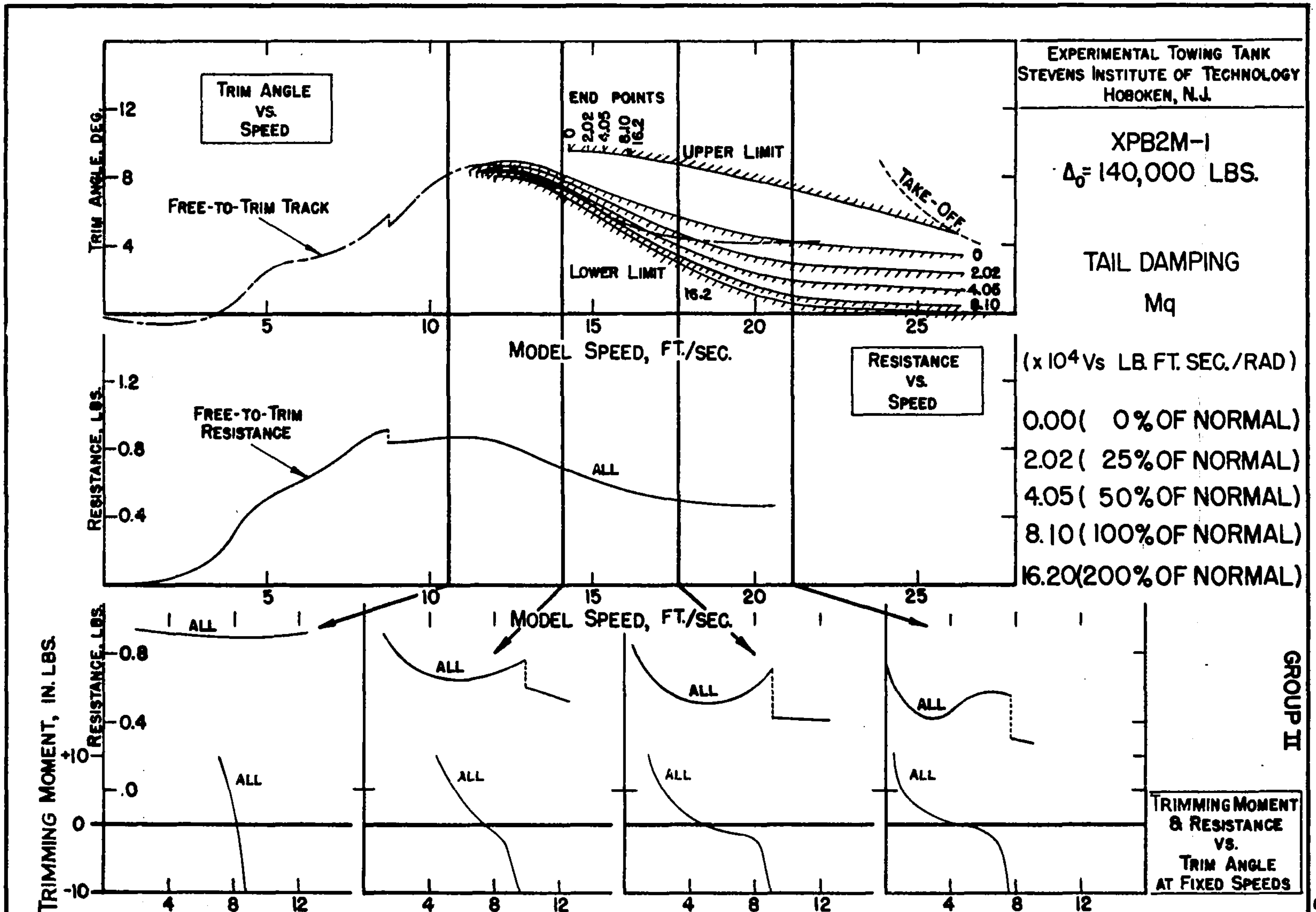

EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0= 140,000 LBS.
TAIL DAMPING
Mq
(x 10⁴ Vs LB. FT. SEC./RAD)
0.00(0% OF NORMAL)
2.02(25% OF NORMAL)
4.05(50% OF NORMAL)
8.10(100% OF NORMAL)
16.20(200% OF NORMAL)
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
END POINTS
UPPER LIMIT
LOWER LIMIT
TAKE-OFF
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
ALL
TRIMMING MOMENT, IN. LBS.
GROUP II
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
TRIM ANGLE, DEG.
NACA

Fig. 13

Fig. 13

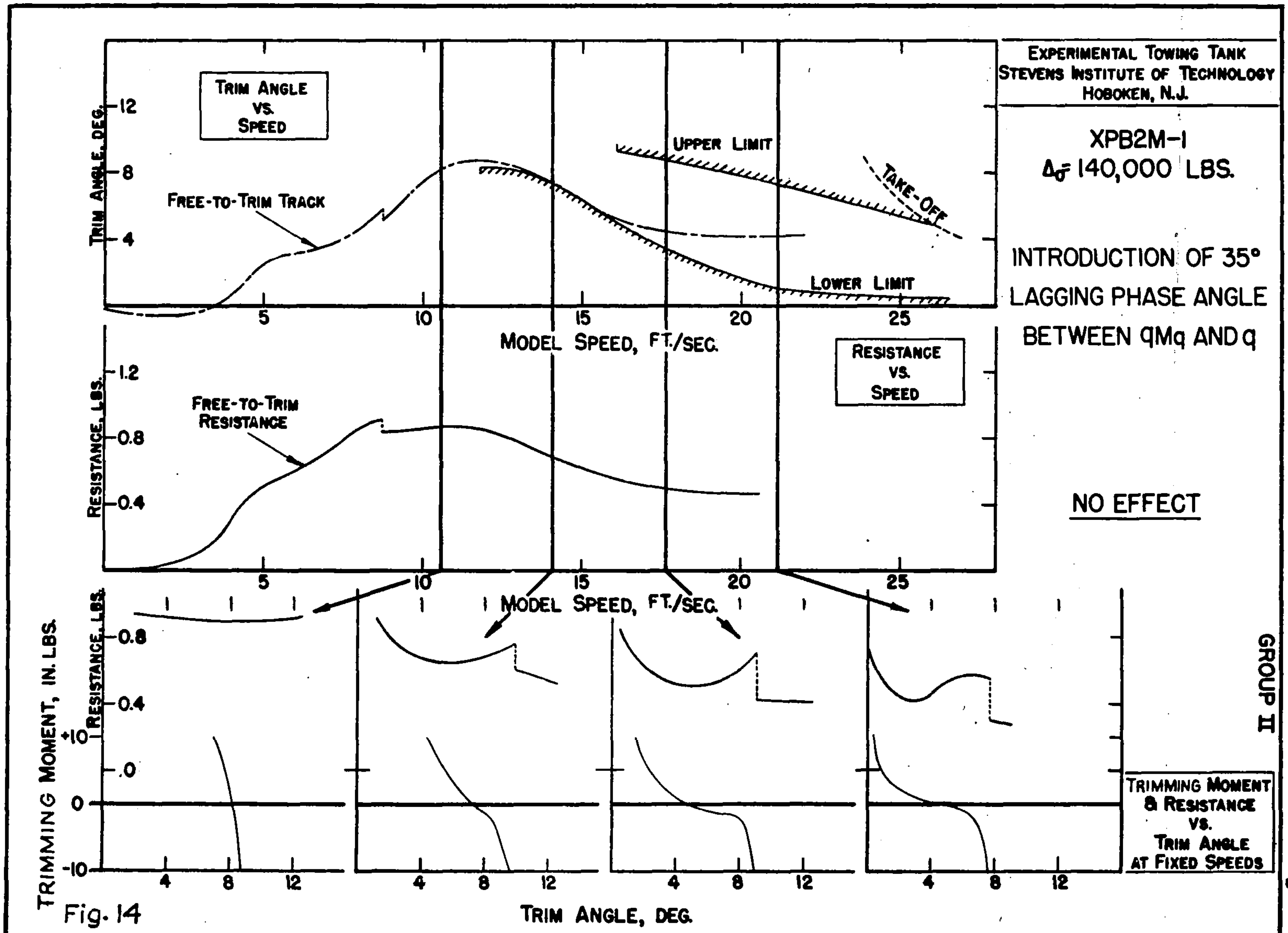


Fig. 14

NACA

Fig. 14

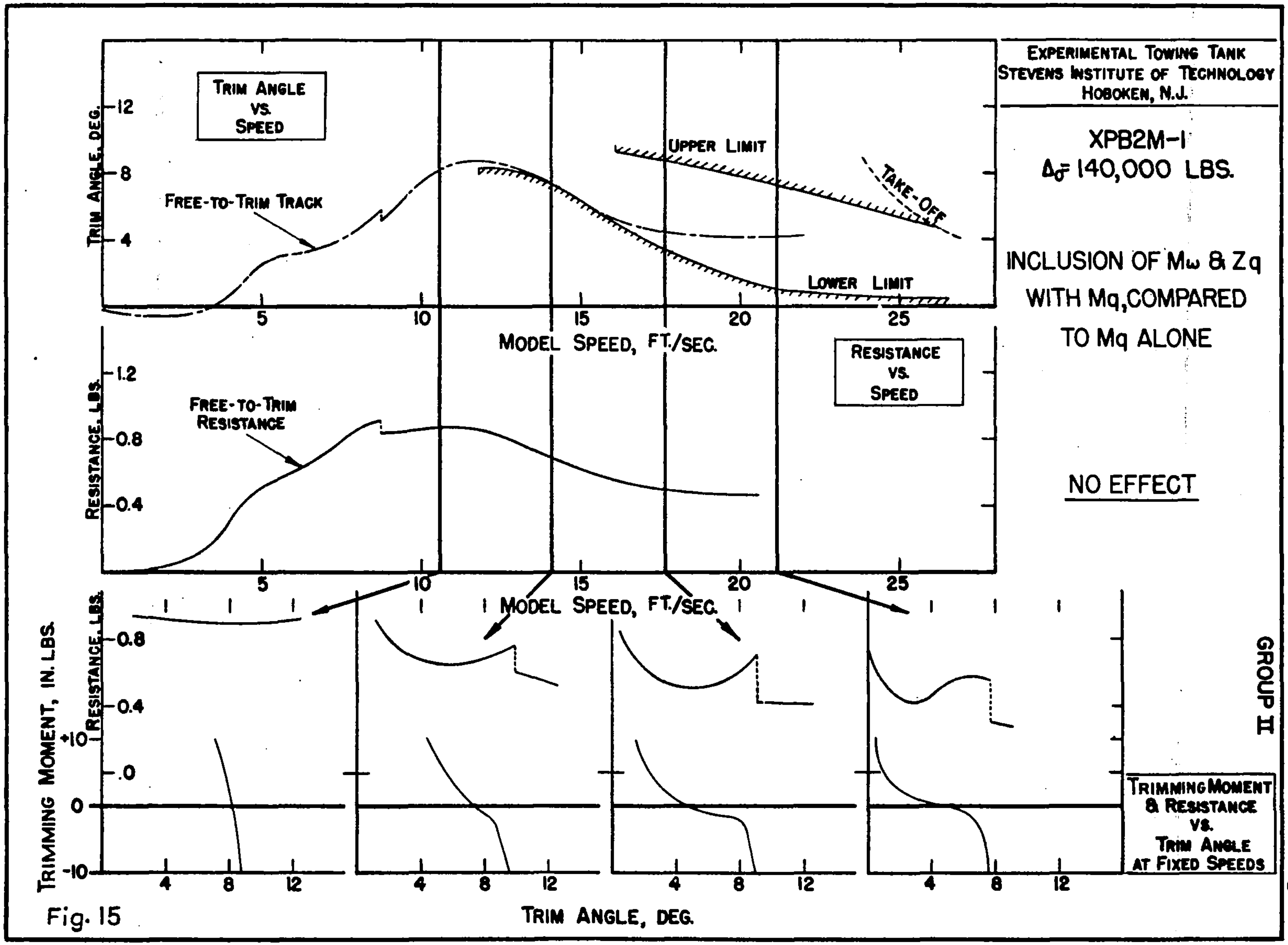
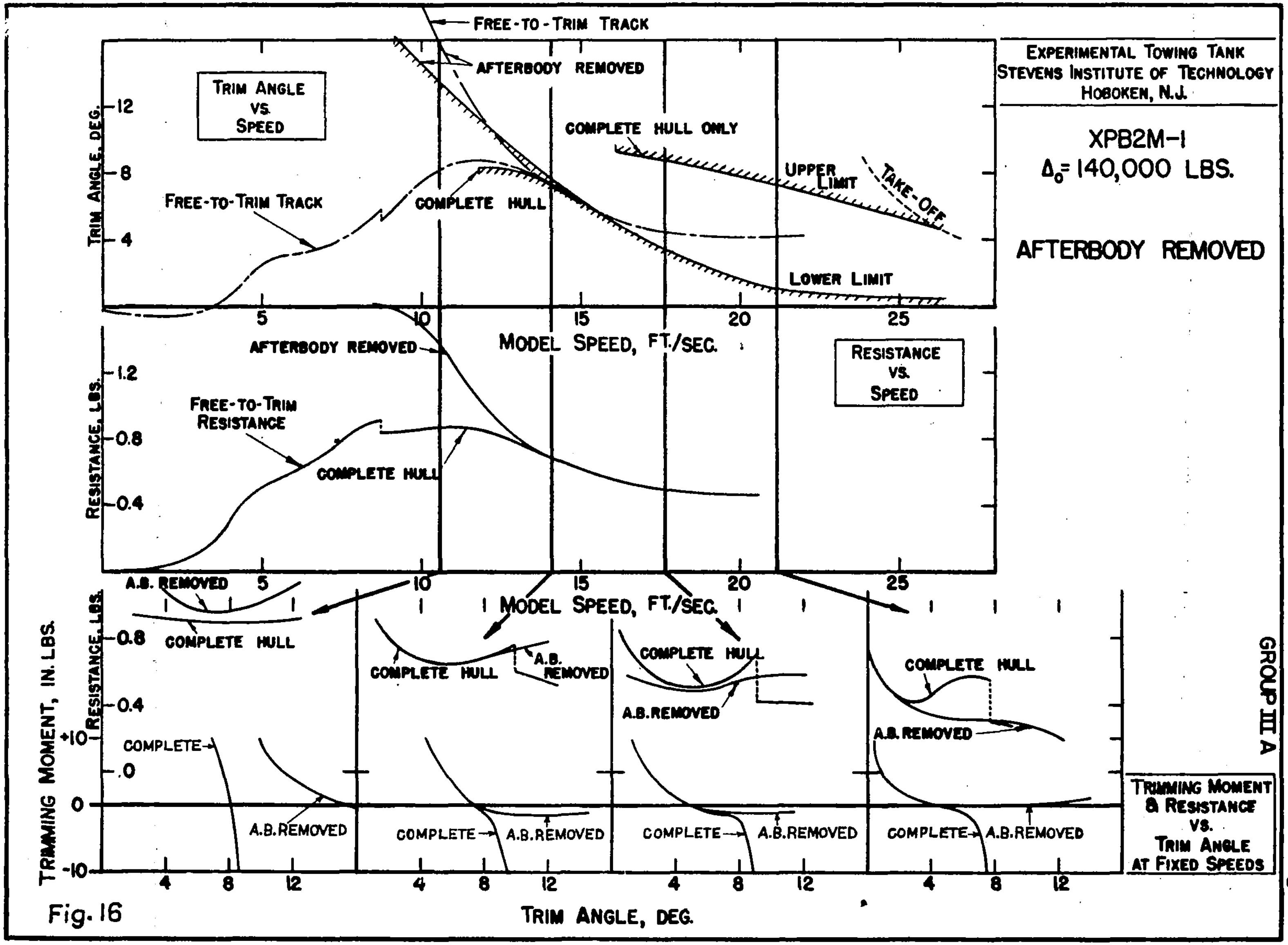


Fig. 15

NACA

Fig. 15



EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0 = 140,000 LBS.
AFTERBODY REMOVED
FREE-TO-TRIM TRACK
AFTERBODY REMOVED
TRIM ANGLE VS. SPEED
COMPLETE HULL ONLY
UPPER LIMIT
TAKE-OFF
FREE-TO-TRIM TRACK
COMPLETE HULL
LOWER LIMIT
TRIM ANGLE, DEG.
MODEL SPEED, FT./SEC.
AFTERBODY REMOVED
RESISTANCE VS. SPEED
FREE-TO-TRIM RESISTANCE
COMPLETE HULL
RESISTANCE, LBS.
MODEL SPEED, FT./SEC.
A.B. REMOVED
COMPLETE HULL
COMPLETE HULL
A.B. REMOVED
COMPLETE HULL
A.B. REMOVED
COMPLETE HULL
A.B. REMOVED
RESISTANCE, LBS.
TRIMMING MOMENT, IN. LBS.
COMPLETE
A.B. REMOVED
COMPLETE
A.B. REMOVED
COMPLETE
A.B. REMOVED
COMPLETE
A.B. REMOVED
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
TRIM ANGLE, DEG.
GROUP III A
NACA

Fig. 16

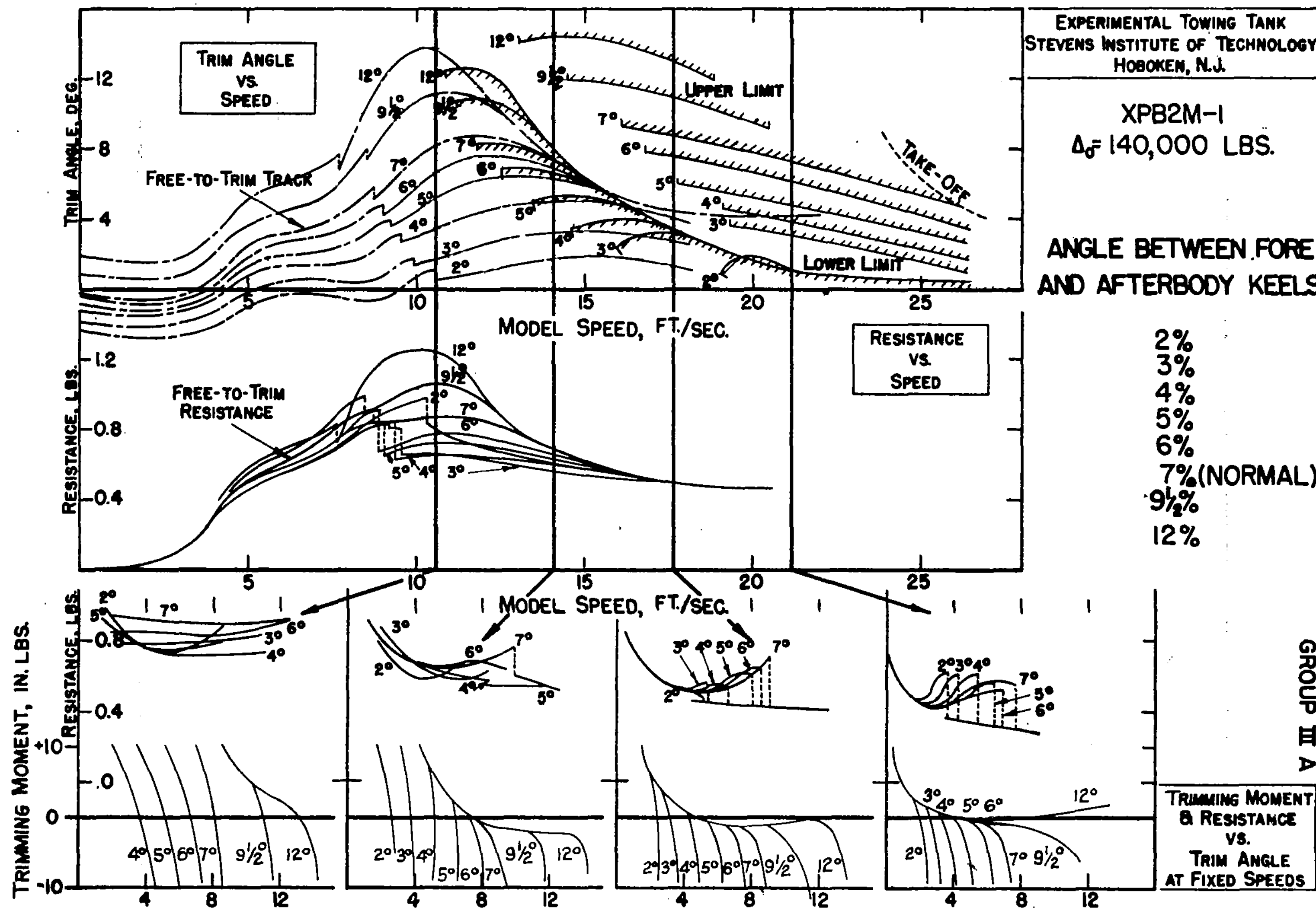
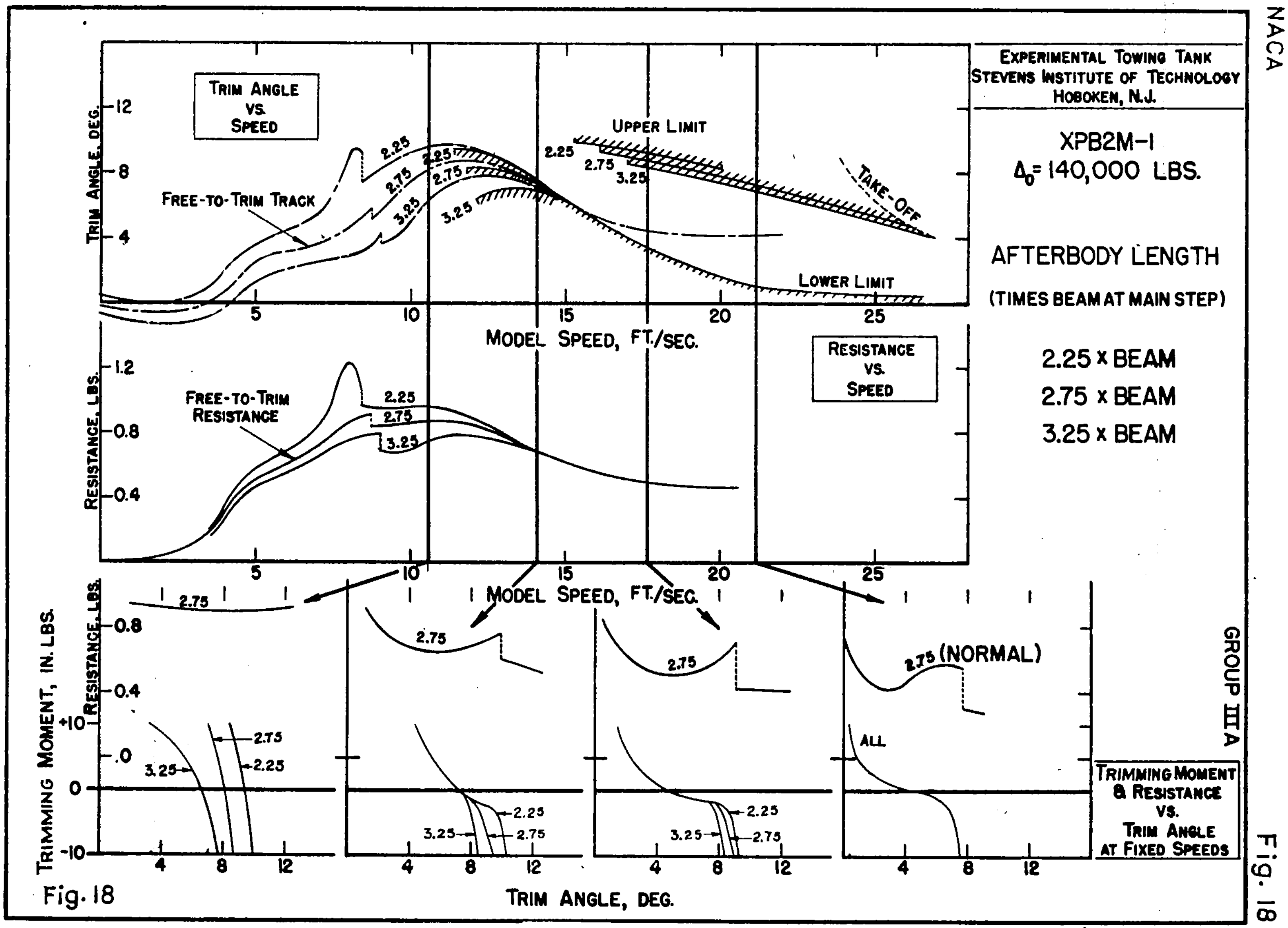


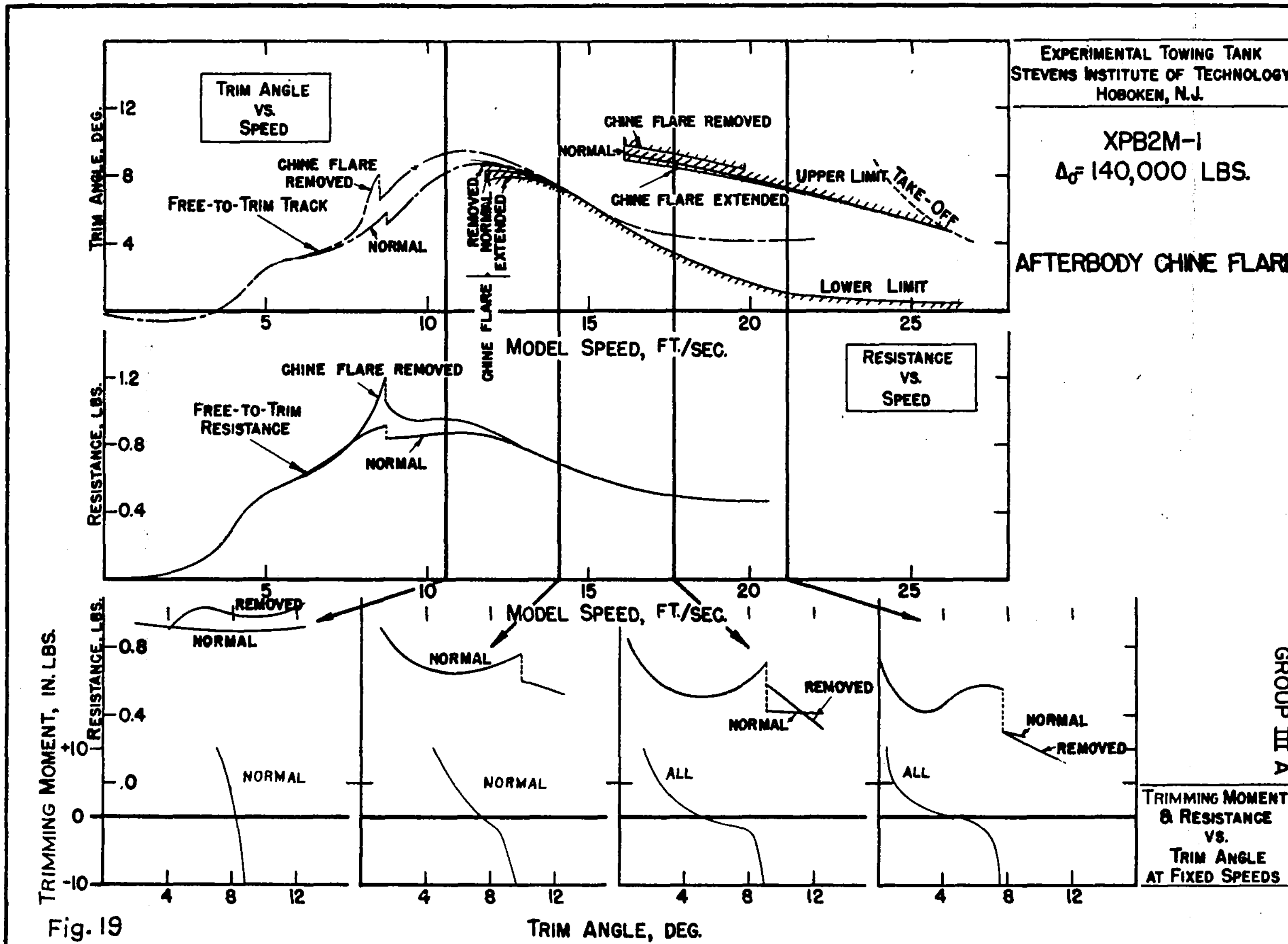
Fig. 17

NACA Fig. 17



EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0 = 140,000 LBS.
AFTERBODY LENGTH
(TIMES BEAM AT MAIN STEP)
2.25 x BEAM
2.75 x BEAM
3.25 x BEAM
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
UPPER LIMIT
LOWER LIMIT
TAKE-OFF
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
TRIMMING MOMENT, IN. LBS.
2.75 (NORMAL)
ALL
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
TRIM ANGLE, DEG.
GROUP IIIA
NACA

Fig. 18



EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ0 = 140,000 LBS.
AFTERBODY CHINE FLARE
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
CHINE FLARE REMOVED
FREE-TO-TRIM TRACK
NORMAL
REMOVED
NORMAL
EXTENDED
CHINE FLARE
CHINE FLARE EXTENDED
UPPER LIMIT
TAKE-OFF
LOWER LIMIT
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
TRIMMING MOMENT, IN. LBS.
ALL
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
TRIM ANGLE, DEG.
GROUP III A
NACA

Fig. 19

Fig. 19

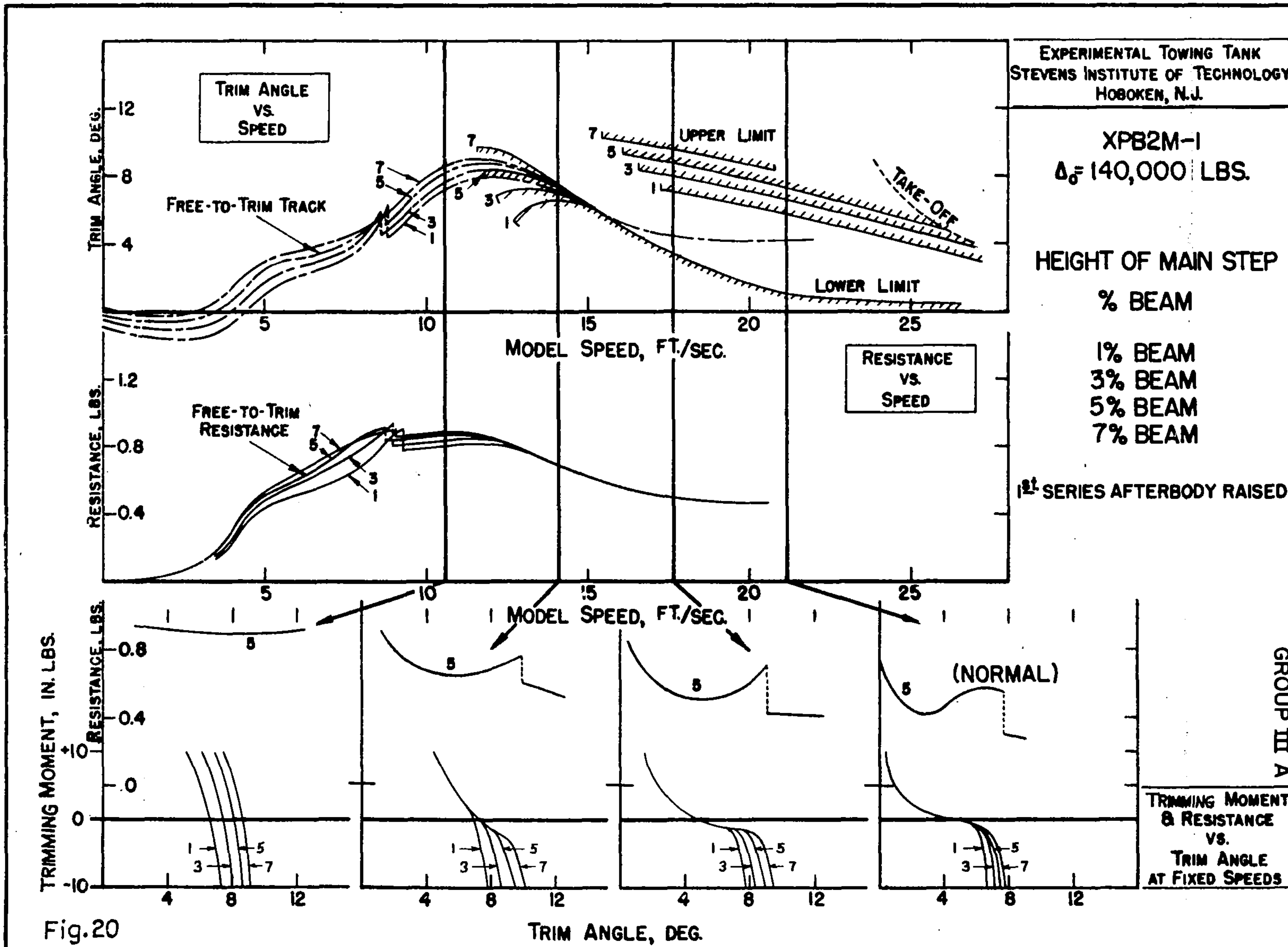

EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0= 140,000 LBS.
HEIGHT OF MAIN STEP
% BEAM
1% BEAM
3% BEAM
5% BEAM
7% BEAM
1st SERIES AFTERBODY RAISED
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
UPPER LIMIT
LOWER LIMIT
TAKE-OFF
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
TRIMMING MOMENT, IN. LBS.
(NORMAL)
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
TRIM ANGLE, DEG.
GROUP III A

Fig. 20

Fig. 20

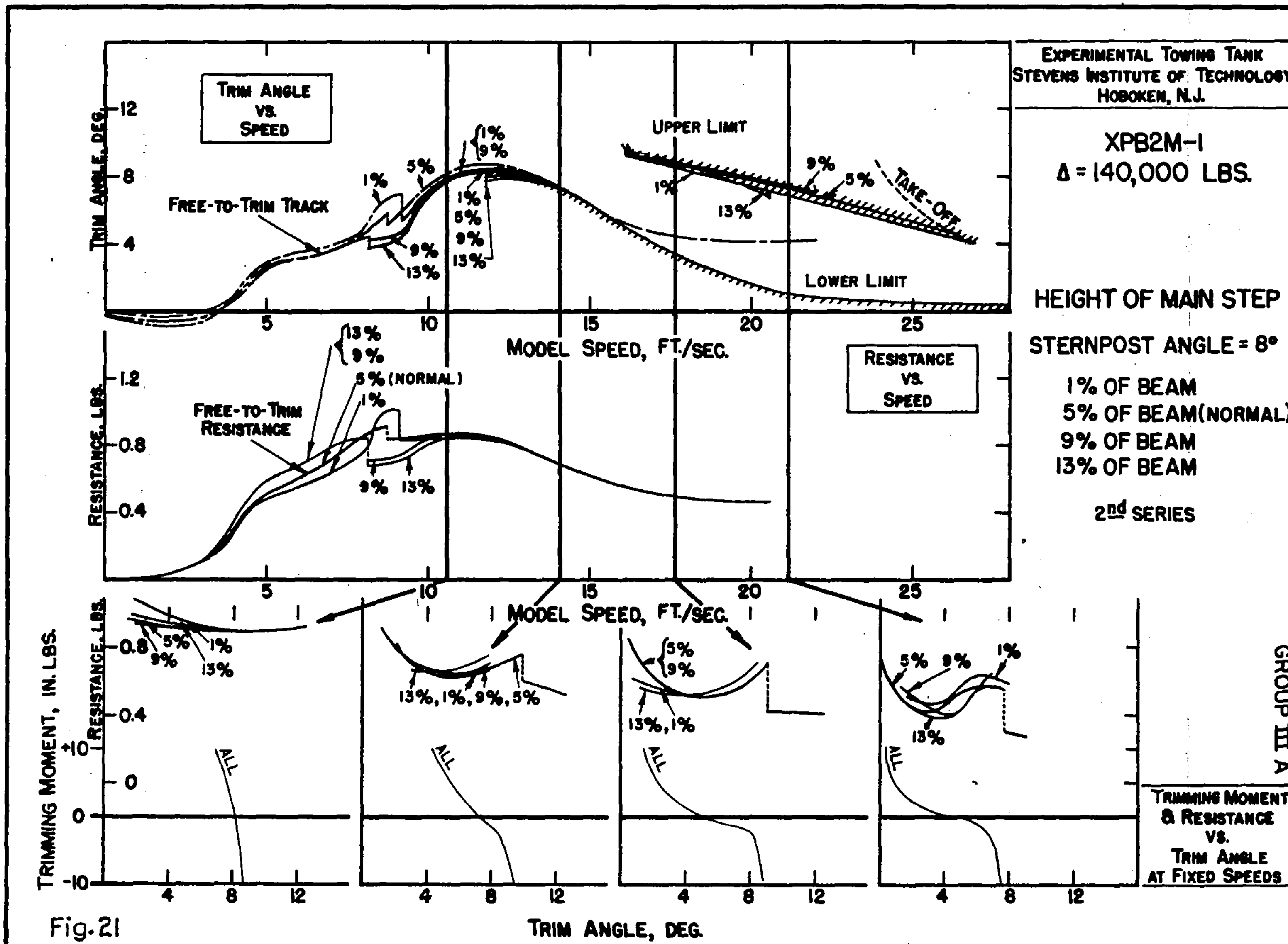
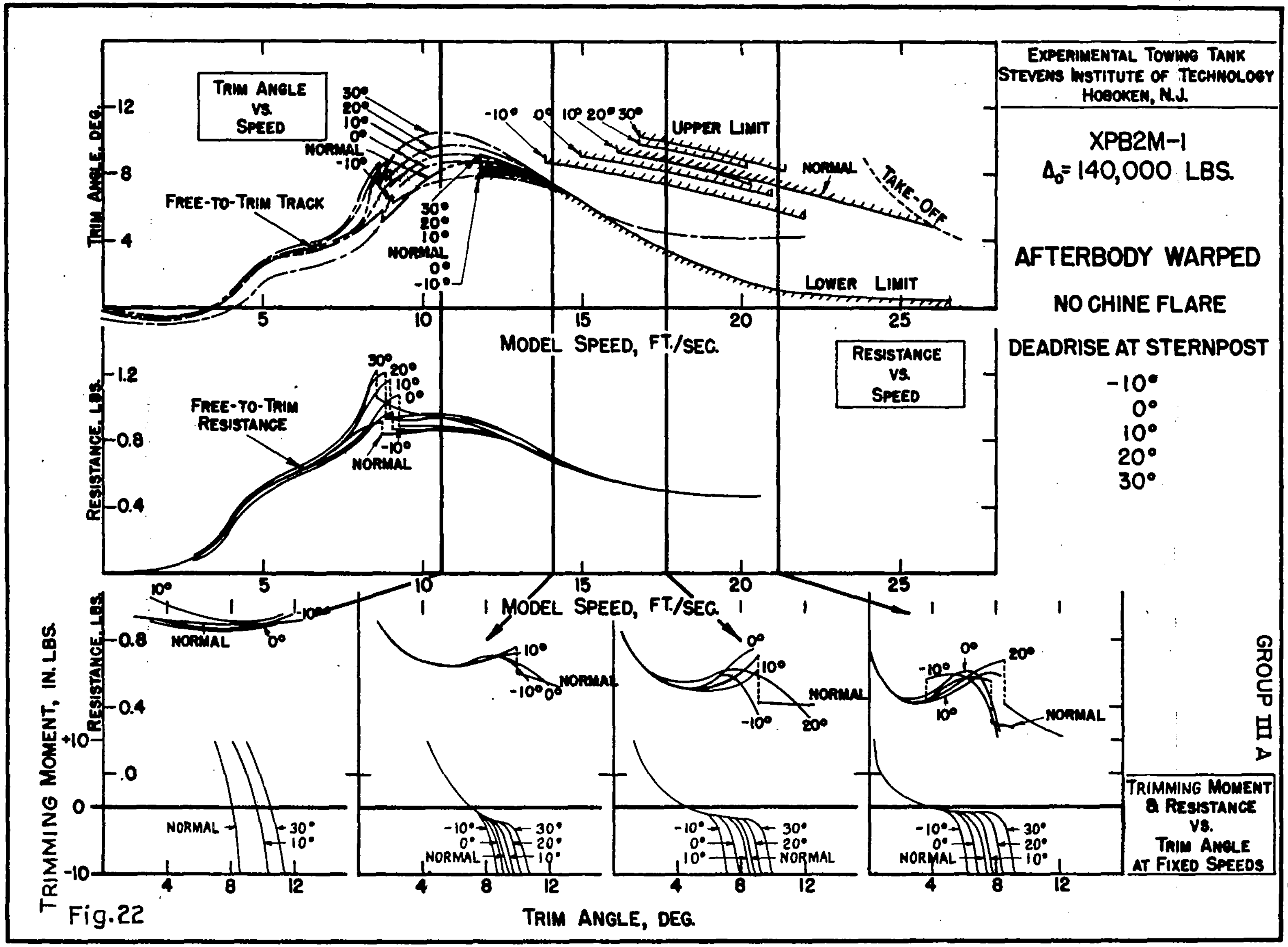

EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ = 140,000 LBS.
HEIGHT OF MAIN STEP
STERNPOST ANGLE = 8°
1% OF BEAM
5% OF BEAM(NORMAL)
9% OF BEAM
13% OF BEAM
2nd SERIES
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
UPPER LIMIT
LOWER LIMIT
TAKE-OFF
1%
5%
9%
13%
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
5% (NORMAL)
TRIMMING MOMENT, IN. LBS.
TRIM ANGLE, DEG.
13%, 1%, 9%, 5%
13%, 1%
ALL
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
GROUP III A

Fig. 21

Fig. 21

NACA



EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0= 140,000 LBS.
AFTERBODY WARPED
NO CHINE FLARE
DEADRISE AT STERNPOST
-10°
0°
10°
20°
30°
TRIM ANGLE VS. SPEED
FREE-TO-TRIM TRACK
UPPER LIMIT
LOWER LIMIT
NORMAL
TAKE-OFF
TRIM ANGLE, DEG.
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
FREE-TO-TRIM RESISTANCE
RESISTANCE, LBS.
TRIMMING MOMENT, IN. LBS.
TRIM ANGLE, DEG.
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
GROUP III A
Fig.22

Fig. 22

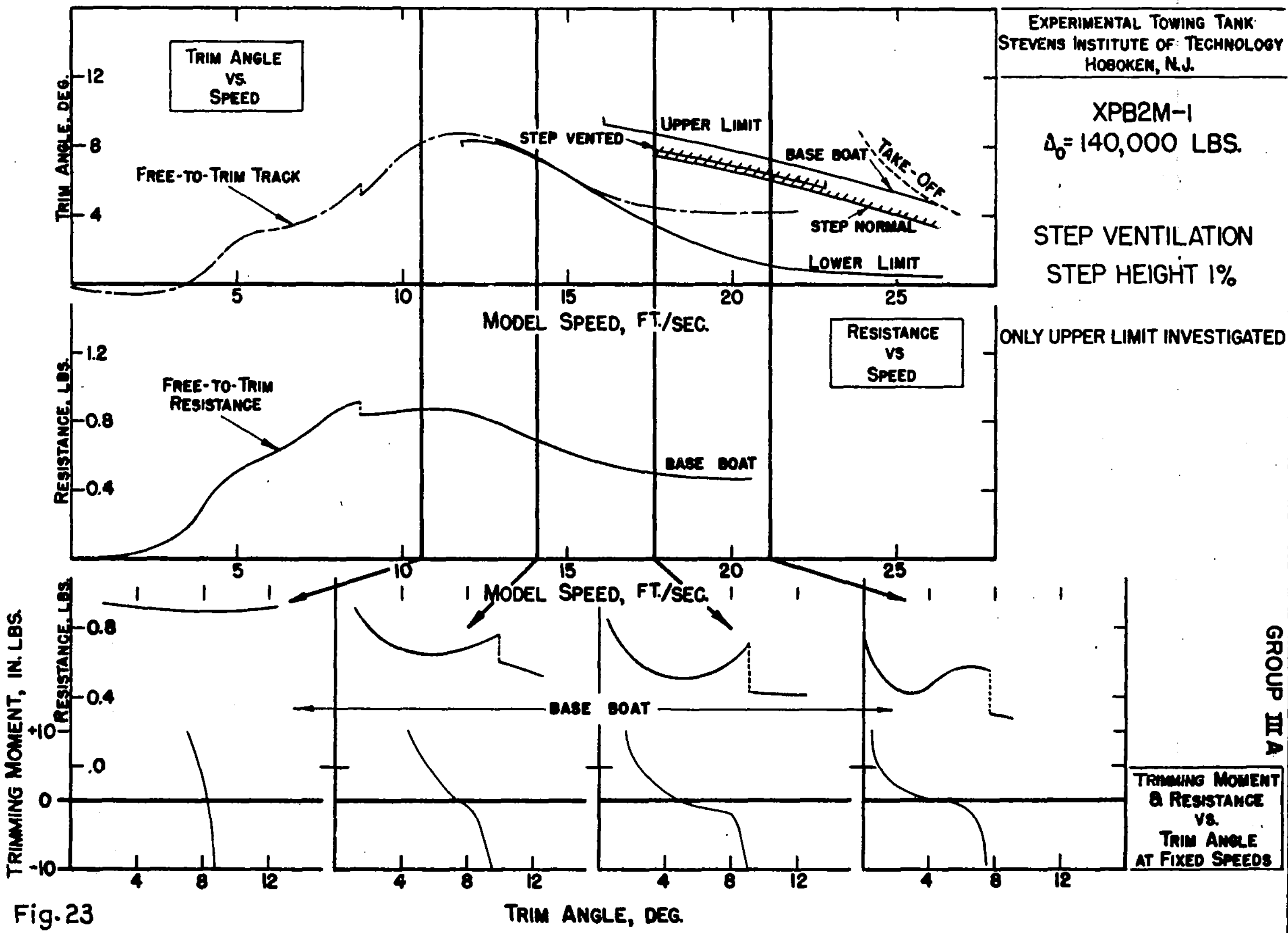
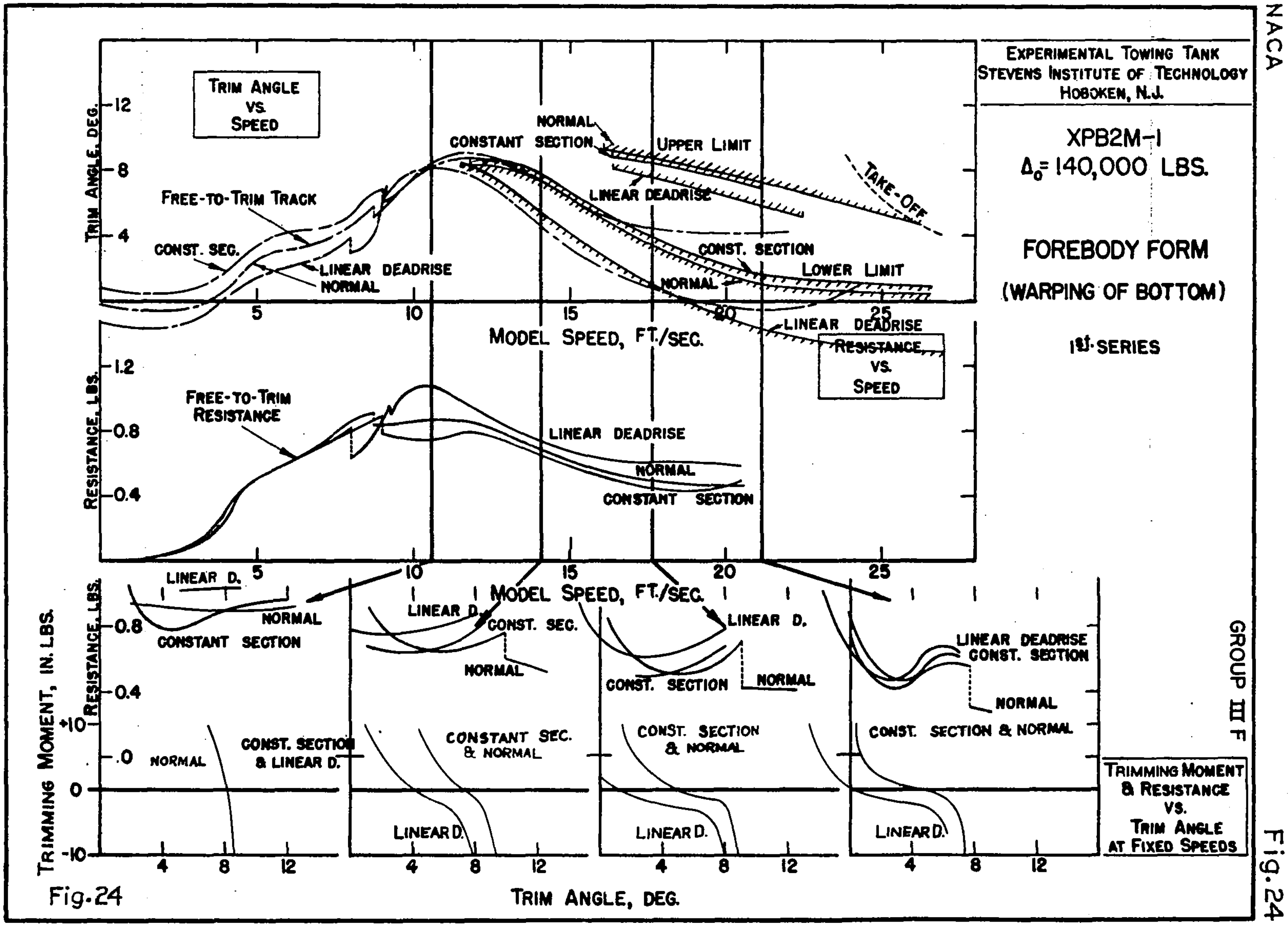

EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ0 = 140,000 LBS.
STEP VENTILATION
STEP HEIGHT 1%
ONLY UPPER LIMIT INVESTIGATED
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
STEP VENTED
UPPER LIMIT
BASE BOAT
TAKE-OFF
STEP NORMAL
LOWER LIMIT
MODEL SPEED, FT./SEC.
RESISTANCE VS SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
BASE BOAT
MODEL SPEED, FT./SEC.
TRIMMING MOMENT, IN. LBS.
RESISTANCE, LBS.
BASE BOAT
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
TRIM ANGLE, DEG.
GROUP III A

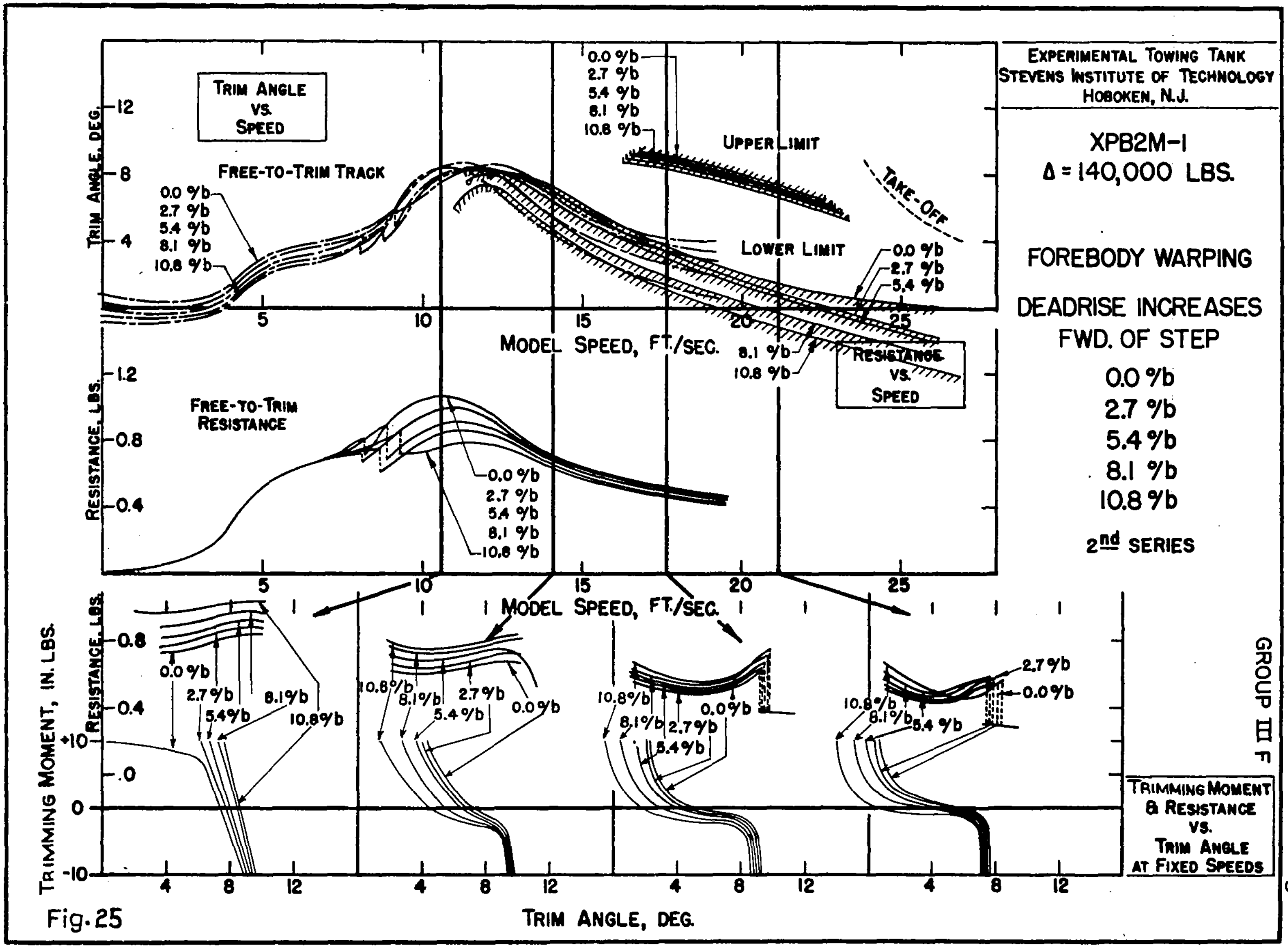
Fig. 23

Fig. 23



EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0= 140,000 LBS.
FOREBODY FORM
(WARPING OF BOTTOM)
1st SERIES
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
CONST. SEC.
LINEAR DEADRISE
NORMAL
CONSTANT SECTION
UPPER LIMIT
TAKE-OFF
CONST. SECTION
LOWER LIMIT
LINEAR DEADRISE
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
LINEAR DEADRISE
NORMAL
CONSTANT SECTION
LINEAR D.
CONSTANT SECTION
CONST. SEC.
CONST. SECTION
CONST. SECTION & NORMAL
CONST. SECTION & LINEAR D.
CONSTANT SEC. & NORMAL
TRIMMING MOMENT, IN. LBS.
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
TRIM ANGLE, DEG.
GROUP III F
NACA

Fig. 24

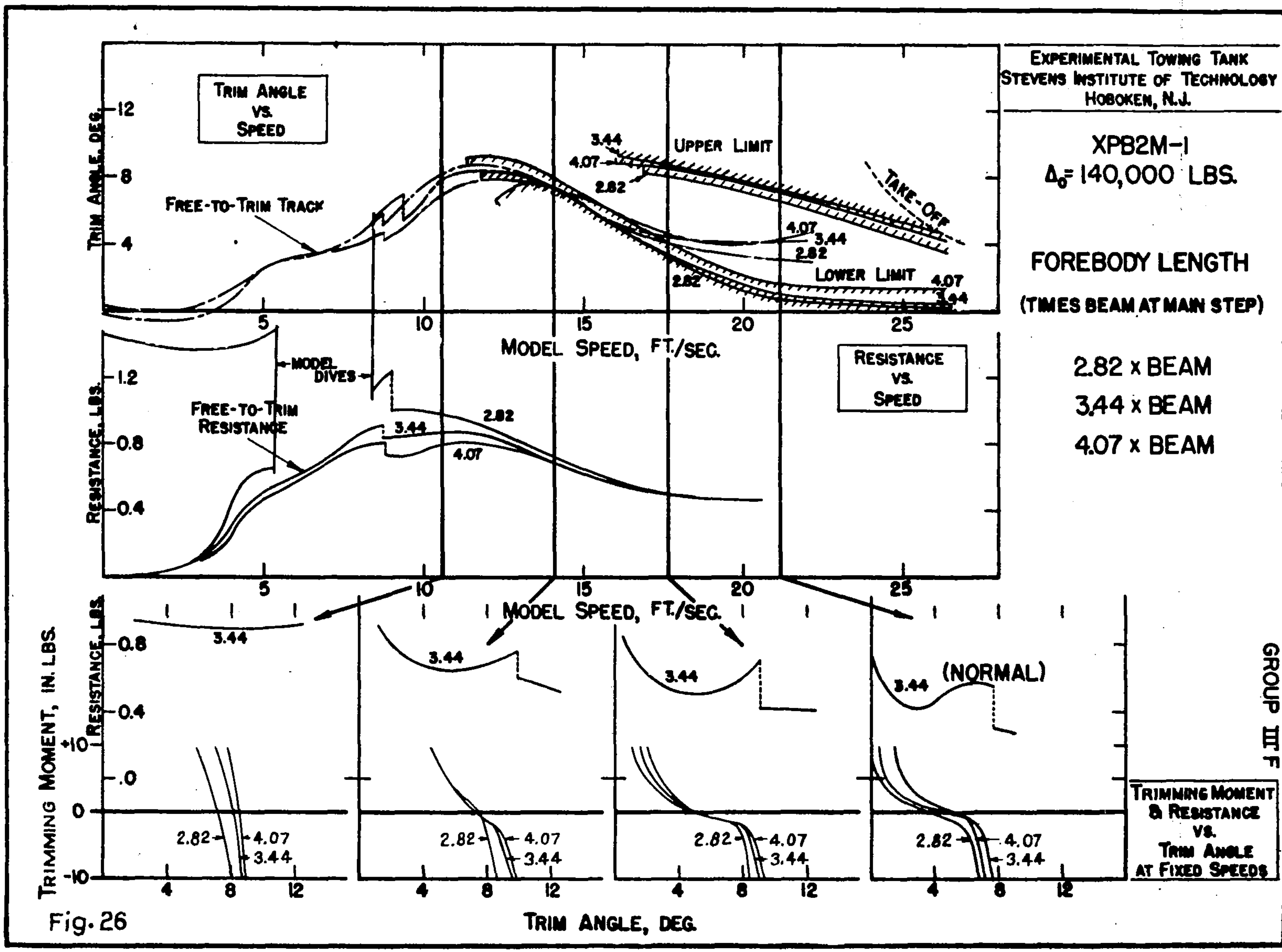


NACA

GROUP III F

Fig. 25

Fig. 25



EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0 = 140,000 LBS.
FOREBODY LENGTH
(TIMES BEAM AT MAIN STEP)
2.82 x BEAM
3.44 x BEAM
4.07 x BEAM
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
UPPER LIMIT
LOWER LIMIT
TAKE-OFF
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
MODEL DIVES
FREE-TO-TRIM RESISTANCE
(NORMAL)
TRIMMING MOMENT, IN. LBS.
TRIM ANGLE, DEG.
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
GROUP III F
NACA

Fig. 26

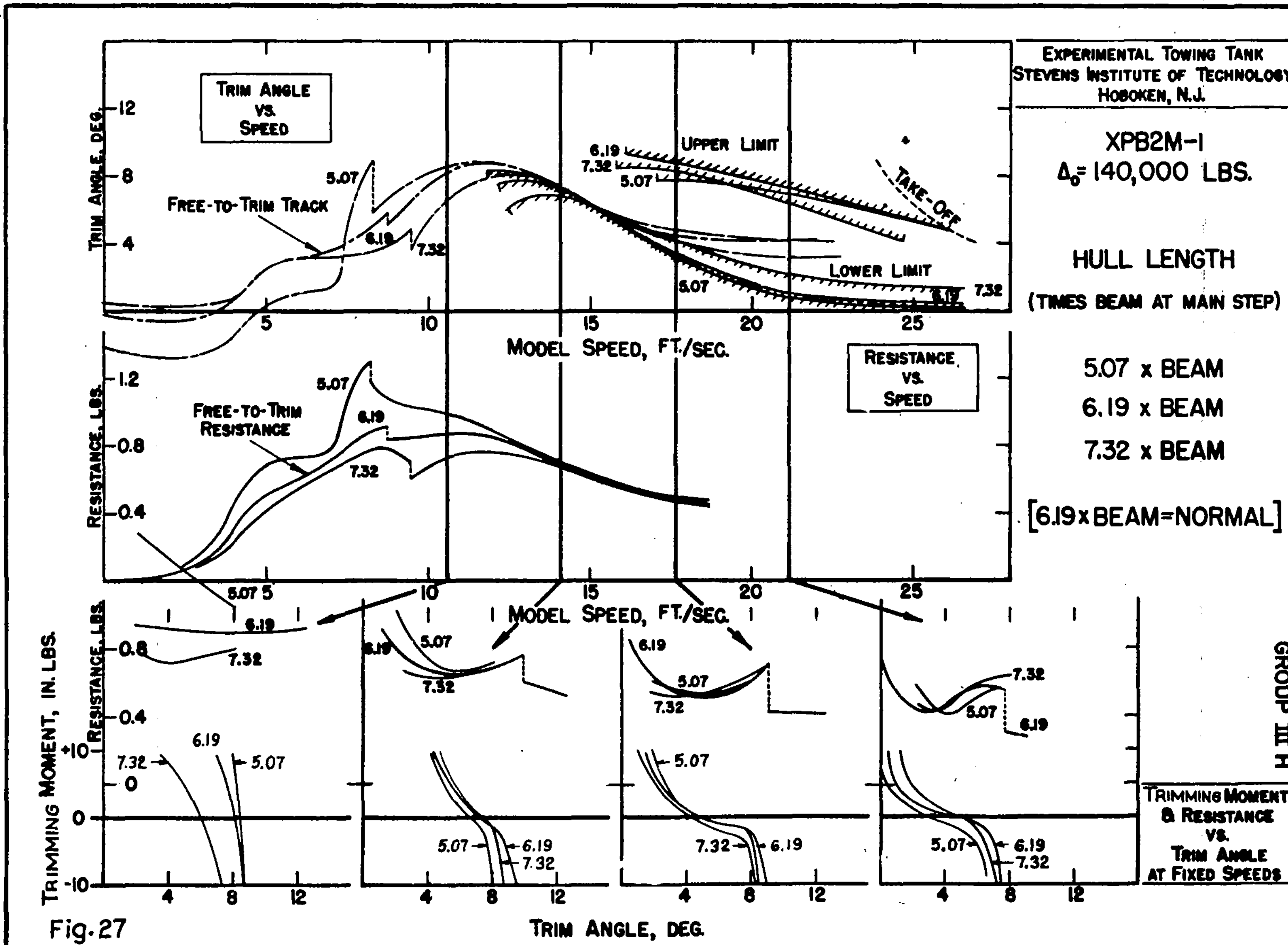

EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ0 = 140,000 LBS.
HULL LENGTH
(TIMES BEAM AT MAIN STEP)
5.07 x BEAM
6.19 x BEAM
7.32 x BEAM
[6.19 x BEAM = NORMAL]
TRIM ANGLE VS. SPEED
FREE-TO-TRIM TRACK
UPPER LIMIT
LOWER LIMIT
TAKE-OFF
TRIM ANGLE, DEG.
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
FREE-TO-TRIM RESISTANCE
RESISTANCE, LBS.
TRIMMING MOMENT, IN. LBS.
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
TRIM ANGLE, DEG.
GROUP III H
NACA
Fig. 27

Fig. 27

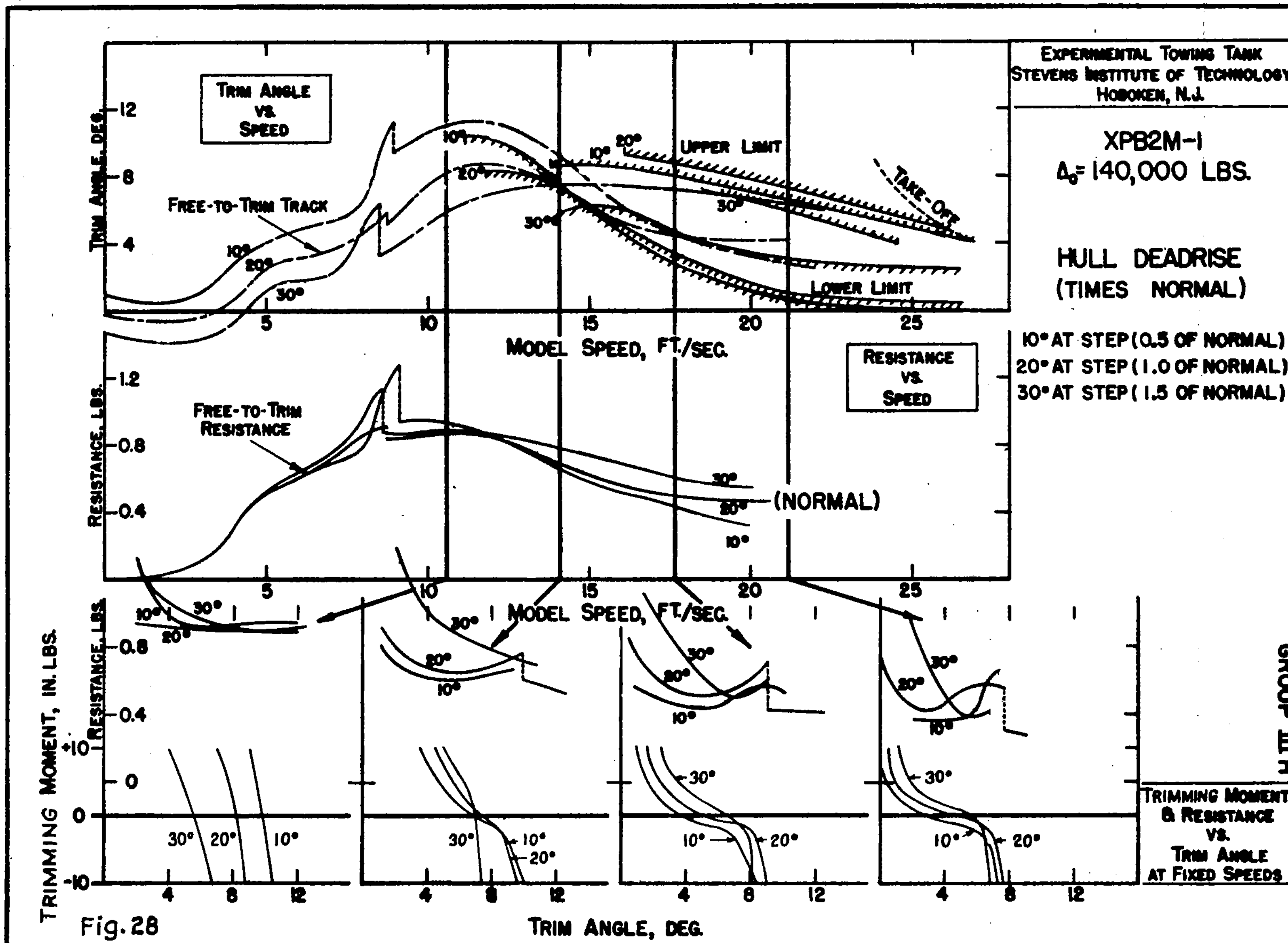
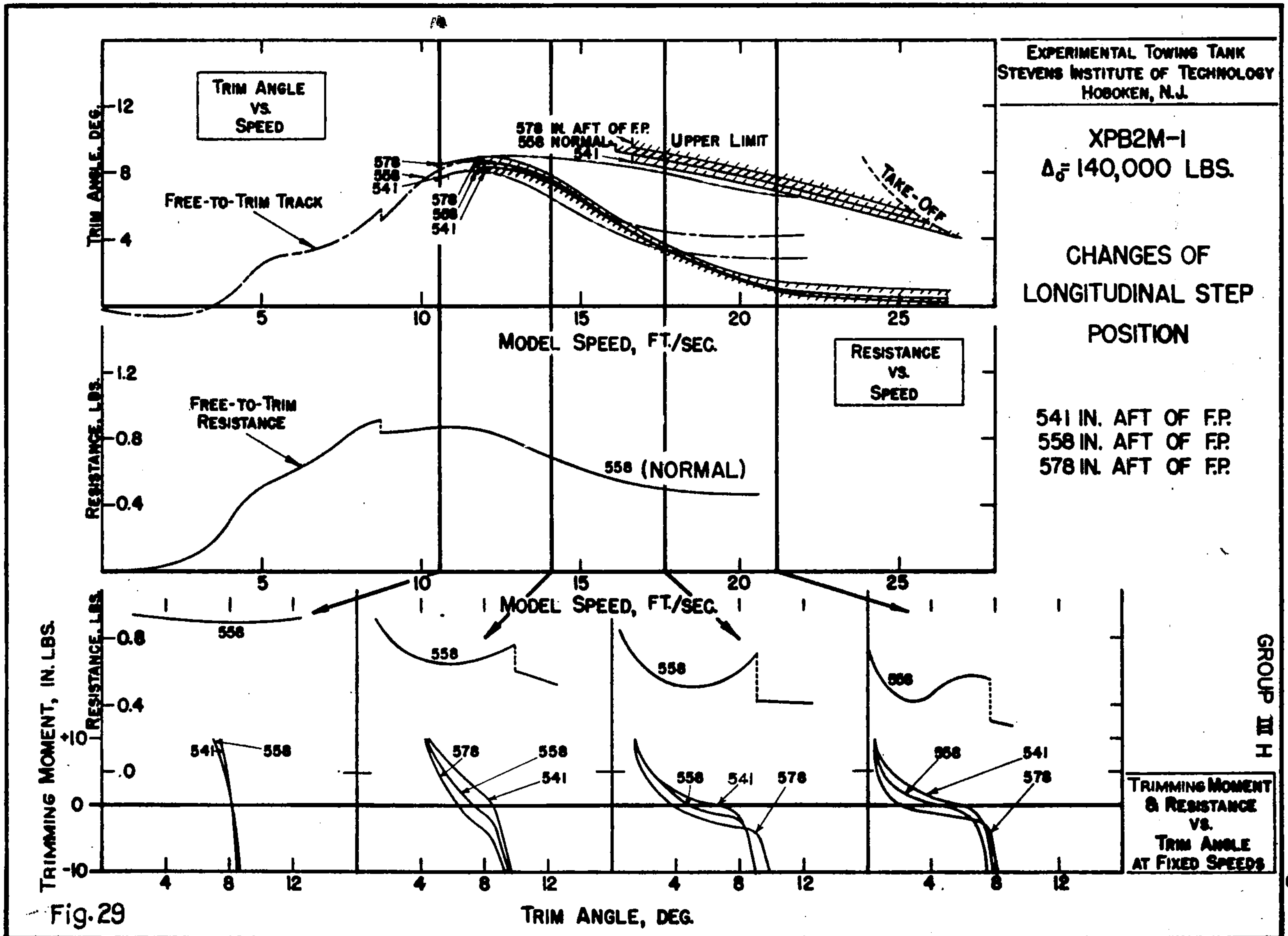


Fig. 28

NACA

Fig. 28



EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ_0 = 140,000 LBS.
CHANGES OF LONGITUDINAL STEP POSITION
541 IN. AFT OF F.P.
558 IN. AFT OF F.P.
578 IN. AFT OF F.P.
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
578 IN. AFT OF F.P.
558 NORMAL
541
UPPER LIMIT
TAKE-OFF
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
558 (NORMAL)
TRIMMING MOMENT, IN. LBS.
TRIM ANGLE, DEG.
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
GROUP III H
NACA

Fig. 29

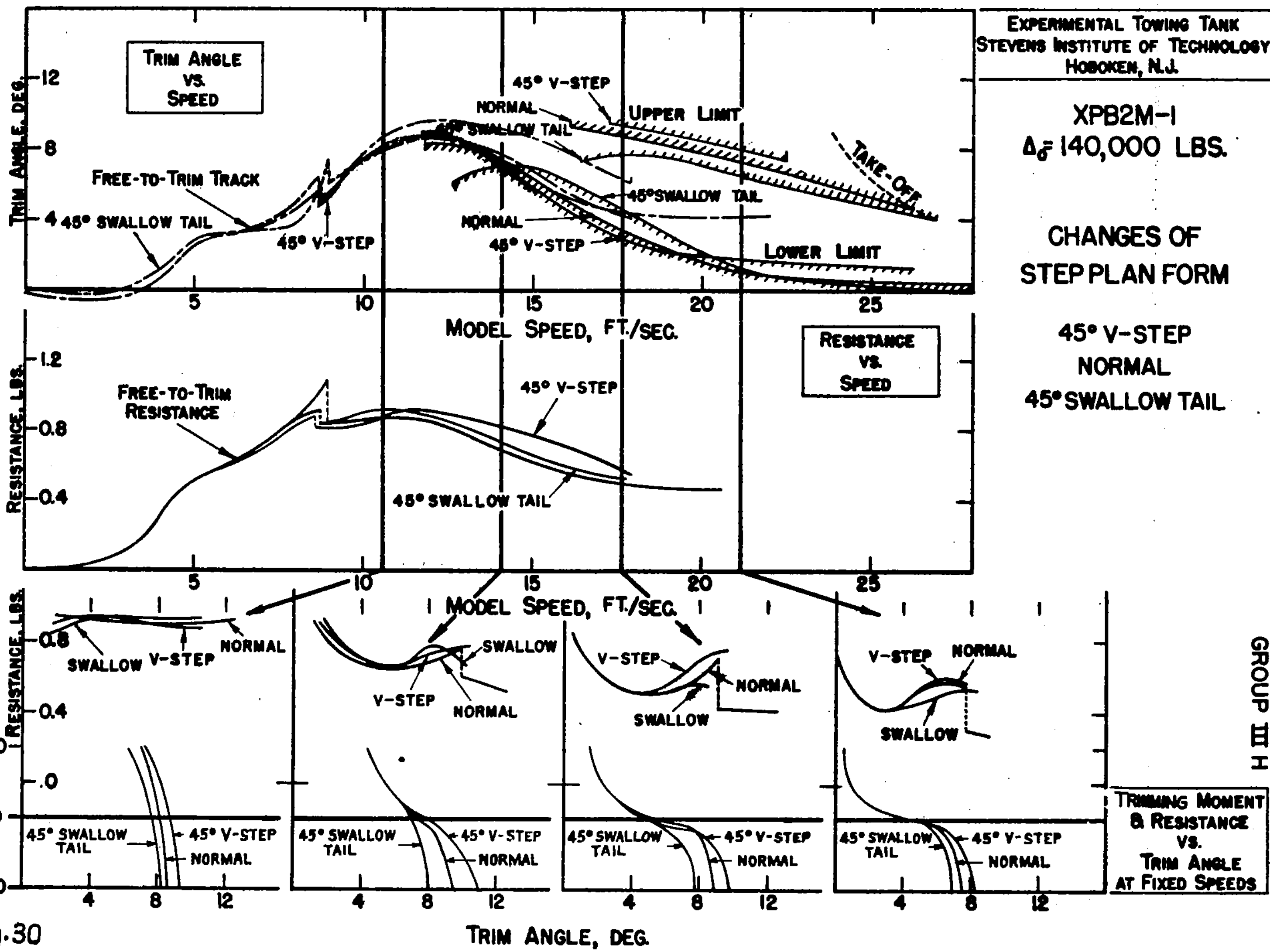
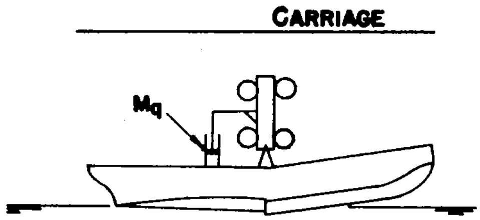
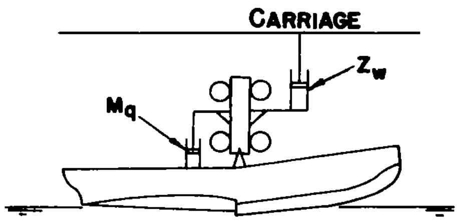

EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
XPB2M-1
Δ₀= 140,000 LBS.
CHANGES OF
STEP PLAN FORM
45° V-STEP
NORMAL
45° SWALLOW TAIL
TRIM ANGLE VS. SPEED
TRIM ANGLE, DEG.
FREE-TO-TRIM TRACK
45° SWALLOW TAIL
45° V-STEP
NORMAL
UPPER LIMIT
LOWER LIMIT
TAKE-OFF
MODEL SPEED, FT./SEC.
RESISTANCE VS. SPEED
RESISTANCE, LBS.
FREE-TO-TRIM RESISTANCE
TRIMMING MOMENT, IN. LBS.
SWALLOW
V-STEP
TRIMMING MOMENT & RESISTANCE VS. TRIM ANGLE AT FIXED SPEEDS
TRIM ANGLE, DEG.
GROUP III H

Fig.30

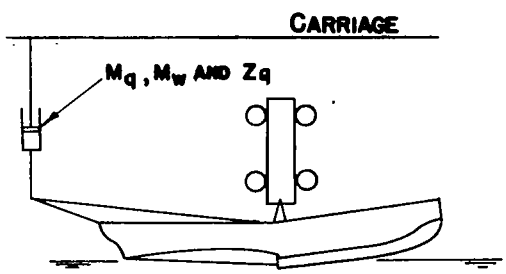
Schematic Sketches Showing Arrangement of Apparatus for Various Types of Damping



FOR TAIL DAMPING DERIVATIVE Mq ONLY
SEE PAGE 20



FOR TAIL DAMPING Mq AND VERTICAL VELOCITY DAMPING Z_w
SEE PAGE 20



FOR TAIL DAMPING Mq, AND THE AERODYNAMIC MOMENTS AND FORCES ATTRIBUTABLE TO M_w AND Zq

FIG. 31
SEE PAGE 22

NACA

GROUP IIIA AFTERBODY MODIFICATION

Fig. 32

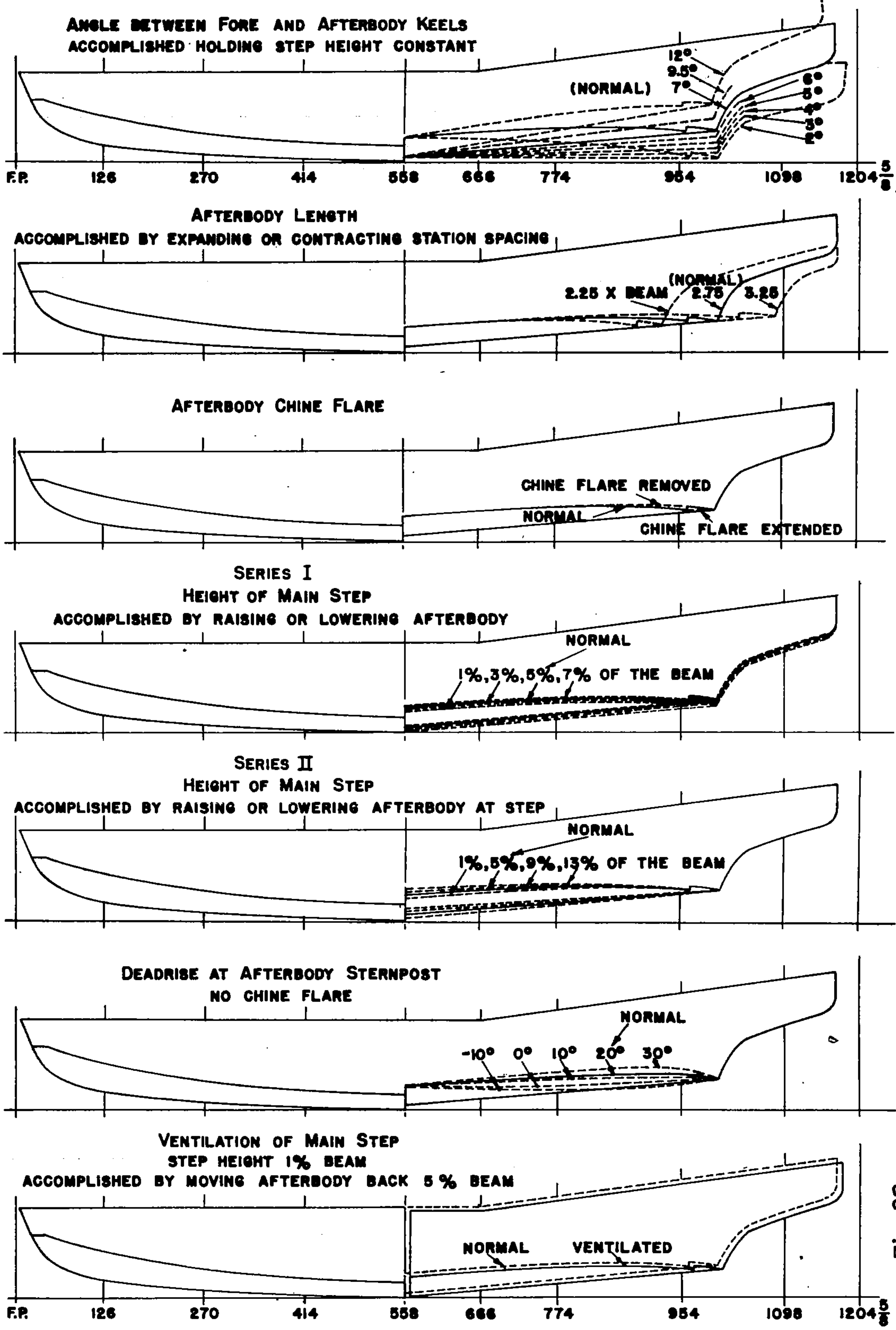


Fig. 32

NACA

GROUP III F & H, FOREBODY & HULL CHANGES

Fig. 33

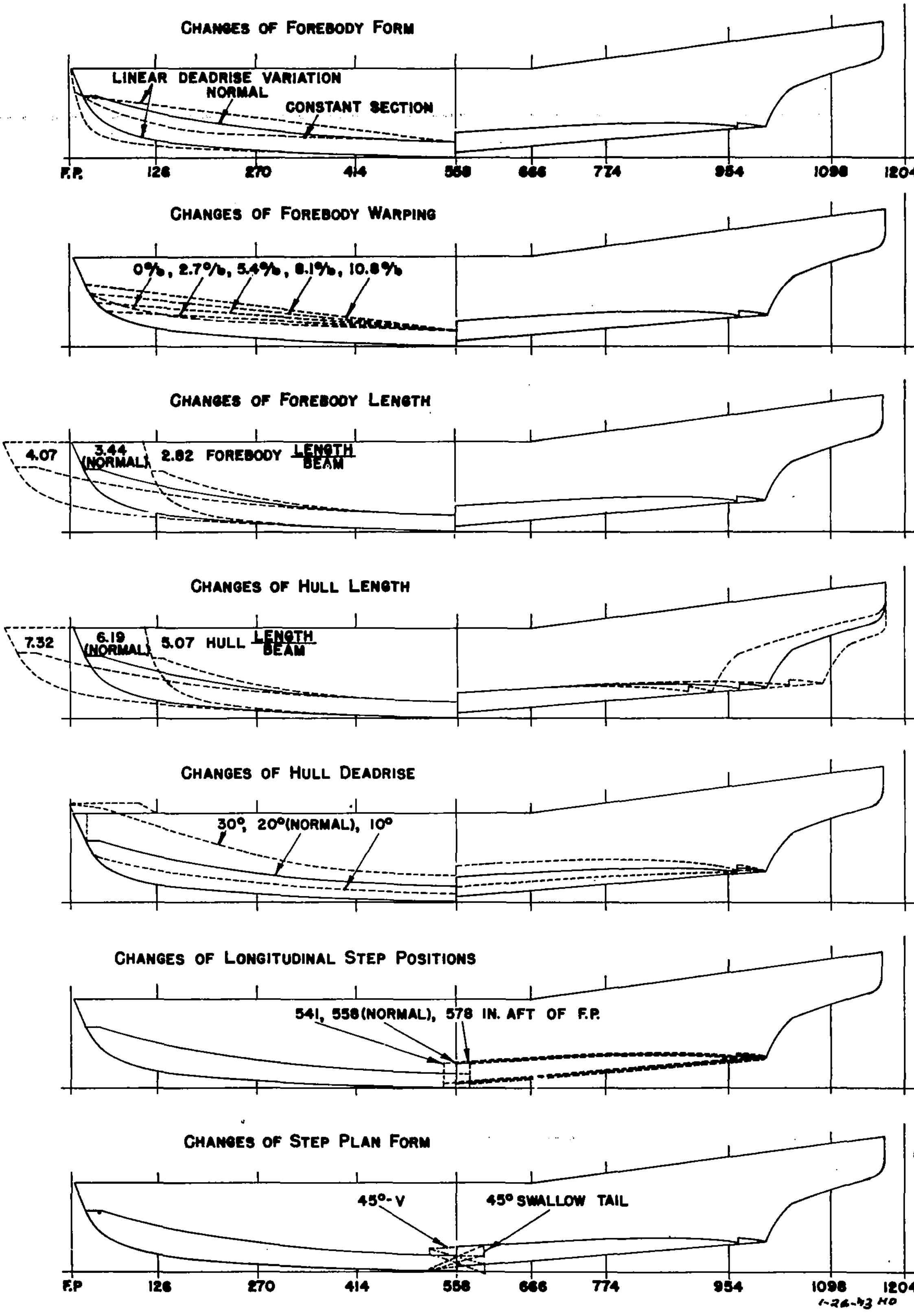


Fig. 33